SEDIMENTOLOGY AND GEOCHEMISTRY OF THE SINGA FORMATION SUCCESSION AT TELUK CHEK DENDANG, LANGKAWI

By

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CERTIFICATION OF APPROVAL

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Approved by,

____

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TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

JULIZA BINTI REHAN

ABSTRACT

The Upper Devonian – Lower Permian Singa Formation of the Langkawi Island consists of black and dark-grey carbonaceous mudstone and siltstone and interbedded lighter quartzite. A detailed sedimentological study and facies analysis of the Singa Formation at Teluk Chek Dendang, Langkawi was conducted to determine the possible palaeo-depositional environment. Two stratigraphic sections of the Singa Formation were logged at Teluk Chek Dendang and one at Tanjung Malai. The sections were divided into facies based on lithology and sedimentary structures. Five different types of facies are identified: 1) Massive siltstone facies-F1; 2) Finely laminated siltstone facies-F2; 3) Thick laminated mudstone facies-F3; 4) Finely laminated mudstone facies-F4; and 5) Black mudstone facies-F5. The succession encountered in the Singa Formation at Teluk Chek Dendang have been divided into two coarsening upward facies association. The facies association grades upward from an offshore facies association (FA 1) composed of black mudstone and finely laminates mudstone facies, into a lower shoreface facies association (FA 2) composed of finely lamination siltstone and massive siltstone facies. Mineral and micro-sedimentary structures are identified through petrographic analysis. The main constituents of the Singa Formation at Teluk Chek Dendang are clay minerals and silt-grade quartz grains. Micro-sedimentary structures of Singa Formation under polarizing microscope possesses fine lamination between mud and siltstone. Erosional features – scours are seen under thin section with slightly coarser sediment occurs within the scours. The geochemistry analysis also proved the rocks of Singa Formation consists of mainly Quartz (SiO_2) and clay minerals. The facies succession is interpreted as coastal depositional environment, specifically the prodelta depositional environment.

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Langkawi Island is located within the Northwestern Domain of Peninsula Malaysia together with Perlis and North Kedah. The most complete sequence of Palaeozoic sedimentary rocks, ranging in age from Upper Cambrian to Upper Permian is exposed in the Northwestern Domain of the Western Belt, in Langkawi, Kedah and Perlis (Lee, 2009).

Singa Formation is describe as the dark grey argillaceous formation, which overlying the Langgun Redbeds and other transitional units above the Setul Group (Lee, 2009). These dark-coloured strata of a thick succession of black siltstone and interbedded lighter coloured quartzite can be distinguished in the Langkawi Island at Singa Islands, southwest of Kuah and the south and east slope of Gunung Raya (Jones, 1981). The equivalent succession of lighter coloured strata on the mainland is known as Kubang Pasu Formation which covers central and east Perlis and the north of Kedah (Jones, 1981).

Singa Formation in Langkawi Islands appear to be unconformably overlaps the Lower Palaeozoic formation and comformably underlies the Chuping Limestone (Jones, 1981). Therefore, the relative age for Singa Formation is between the Carboniferous and Permian age.

According to P. H. Stauffer and Mantajit (1981), pebbly mudstones (‘tilloids’) occur within the Singa Formation. Singa Formation crops out in Langkawi Islands and also in the North Perlis which covers 40 square miles in Perlis and 30 square miles in Langkawi Islands (Jones, 1981).

1.2. PROBLEM STATEMENT

i. The most recent study on the Singa Formation in Langkawi Islands conducted by previous authors was in 1991.
ii. No recent sedimentary facies analysis of the Singa Formation succession at the study area (Teluk Chek Dendang) was conducted.
iii. No palaeo-depositional environment model was proposed at the study area (Teluk Chek Dendang).

Thus, this project is conducted to provide detail information on the sedimentary facies analysis of the Singa Formation succession at Teluk Chek Dendang in Langkawi Islands and proposed the possible environment of deposition at the study area.

1.3. OBJECTIVES AND SCOPE OF STUDY

Objectives

i. Describe and interpret the sedimentary facies of the Singa Formation based on outcrop and petrographic analysis.
ii. Identify facies associations in terms of sedimentary processes and environments.
iii. Identify main composition of the Singa Formation based on geochemistry analysis.
iv. Propose a depositional model taking into account the sedimentological and geochemical characteristics of the Singa Formation.

Scope of study

The main study area is located at Teluk Chek Dendang, Langkawi. The other study area include Tanjung Mali and Tanjung Malai, Langkawi. All of the study area are located at the Southwestern part of the Langkawi Island.

Three outcrops are accessible at the Teluk Chek Dendang study area and seven samples are collected. Three outcrops are accessible at the Tanjung Malai study area and five samples are collected. At Tanjung Mali study area, two outcrops are accessible. Sedimentological study and facies analysis were conducted at the study areas (FIGURE 1).

Laboratory analysis such as petrographic and geochemistry analysis were conducted to the samples taken from the fieldwork.

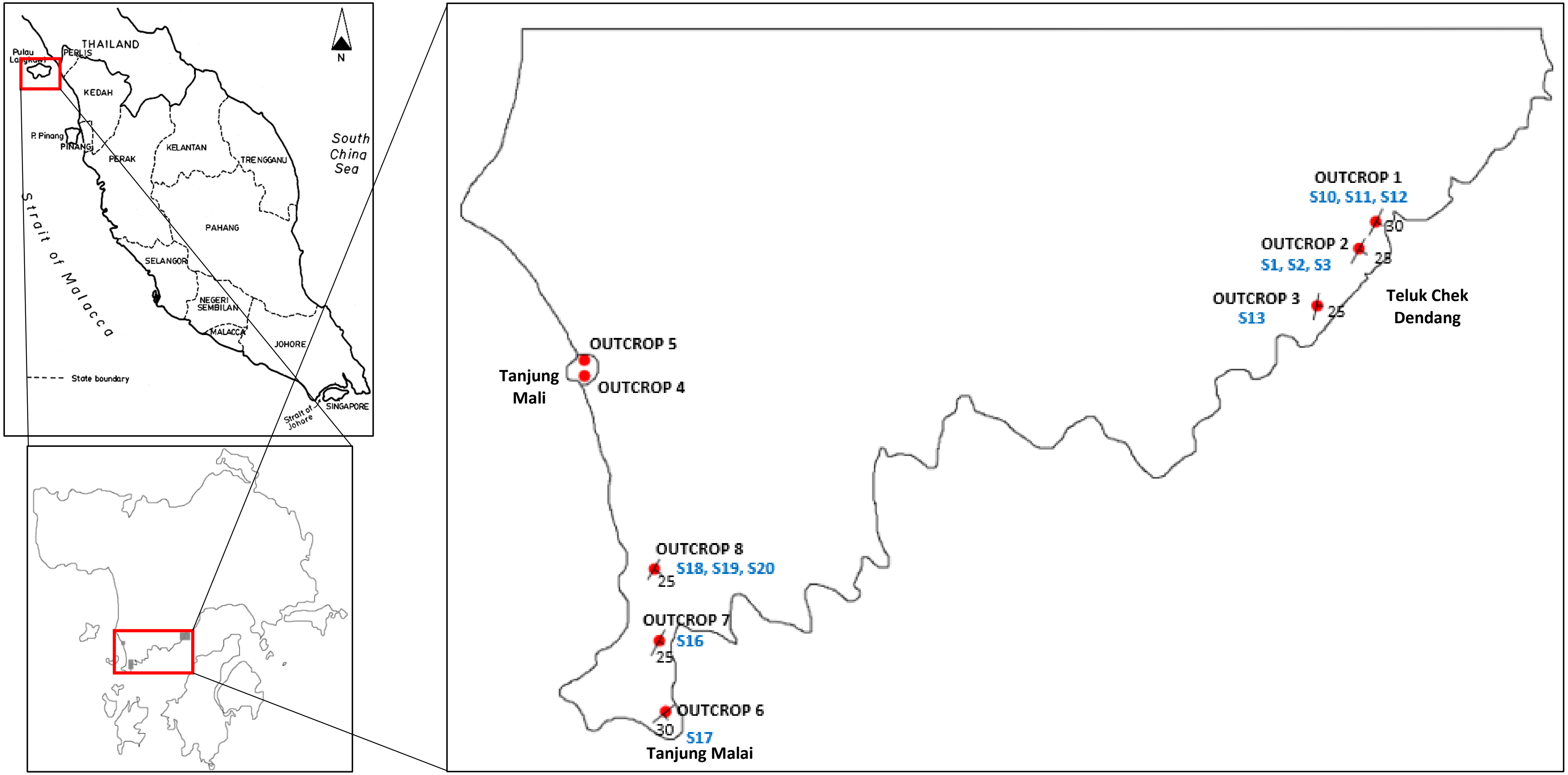


FIGURE 1: Top left: Map of Peninsular Malaysia with emphasis on Langkawi Island. Bottom left: Map of Langkawi Island with emphasis on the study area. Right: Outcrop and sample location map of the study area.

CHAPTER 2

LITERATURE REVIEW

2.1. BACKGROUND

Singa Formation is exposed in Langkawi Island and in north Perlis. In Langkawi Islands, the Singa Formation comprises a thick succession of black siltstone and interbedded lighter coloured quartzite whereas in the north Perlis, it comprises of black and dark-grey carbonaceous mudstone and siltstone and interbedded lighter quartzite (Jones, 1981).

The exposure of Singa Formation is about 1000 feet on the Singa Islands and along the promontory to the west of Kuah. At the north of Kuah, a belt of steep hills rising to over 1500 feet forms the eastern foothills of the Gunung Raya (Jones, 1981). Jones (1981) estimated the thickness of the Singa Formation is around 6500 feet.

Singa Formation rocks consist mainly of dark-grey or dark well bedded carbonaceous flagstones and siltstones with subordinate grey and brown immature quartzites and subgreywackes (Jones, 1981).

Stauffer and Mantajit (1981) stated that pebbly mudstones (‘tilloids’) also occur within the Singa Formation. The tilloid-bearing units occurs within an orogenic belt extending from the southern Malay Peninsula northwards into southwest China. The tilloids are associated with the ‘miogesynclinal’ (western) portion of this belt, in which deformation is only moderate, characterized by open folds and some thrust faults. The tilloid-bearing units have suffered only very slightly metamorphism, shown as a weak cleavage.

2.2. STRATIGRAPHIC UNIT OF PALAEOZOIC SUCCESSION IN NORTWEST PENINSULAR MALAYSIA

The Northwest Domain of Peninsular Malaysia include the Langkawi Islands, Perlis and Kedah are where the most complete sequence of Palaeozoic sedimentary rocks ranging from Upper Cambrian to Upper Permian is exposed (Lee, 2009).

The summary of the stratigraphy of the Northwest region of peninsula Malaysia is shown in stratigraphic chart below.

Period		Perlis	Langkawi & mainland	Perlis & Kedah	Langkawi	
		Meor et al. (2013)	Lee (2009)	Cocks et al. (2005)	Cocks et al.(2005)	Jones (1981)
Permian	Kungurian	Kubang Pasu: Uppermost Kubang Pasu Formation (Perlis) & Singa Formation (Langkawi)				
	Artinskian					
	Sakmarian					
	Asselian					
Carboniferous	Gzhelian					
	Kasimovian					
	Moscovian					
	Bashkirian					
	Serpukhovian	?				
	Visean	Chepor Member	Chepor Formation: Hutan Aji Member	Kubang Pasu Formation	Singa Formation	Singa Formation
	Tournaisian					
Devonian	Famennian	No Record	Chepor Formation: Langgun Redbeds	Jentik Formation	Langgun redbeds	Basal red mudstone
	Frasnian					
	Givetian					
	Eifelian					
	Emsian	Timah Tasoh Formation	Timah Tasoh Formation			
	Praghian				Timah Tasoh Formation	Upper Detrital Member
	Lochkovian					
Silurian	Pridolian	Mempelam Limestone	Mempelam Limestone	Mempelam Limestone	Mempelam Limestone	Upper Setul Limestone
	Ludlovian					
	Wenlock					
	Llandovery		Tanjong Dendang Formation	(Not exposed)	Tanjong Dendang Formation	Lower Detrital Member
Ordovician	Ashgill				Red lst.	
	Caradoc		Kaki Bukit Limestone	Kaki Bukit Limestone	Kaki Bukit Limestone	Lower Setul Limestone
	Llandeil					
	Llancirn					
	Arenig					
	Tremadoc		Machinchang Formation	Jerai Formation	Machinchang Formation	Machinchang Formation
Cambrian	Upper					
			? Datai Beds ?	? ? ?	? ? ?	? ? ?

FIGURE 2: Summary of the stratigraphy of the NW of peninsula Malaysia. Thickness of the formations is not scale (modified from Meor *et al*., 2013; Lee, 2009; Cocks *et al*., 2005; Jones, 1981)

2.3. SINGA FORMATION SUCCESSION IN THE NORTHWEST DOMAIN OF PENINSULA MALAYSIA

As mentioned previously, the Singa Formation is outcrops at the north of Perlis and in Langkawi Islands.

The base of the Singa Formation in the Langkawi Island is defined by the red conglomerate mudstone with late Devonian fossils which unconformably overlies the Timah Tasoh Formation (previously known as Upper Detrital Member) on Pulau Langgun. However, in Perlis, the unconformity is not observed in outcrop but in the Sungei Bunut north of Kaki Bukit where the Singa strata occur in close proximity to the Setul limestone, thus an unconformity can be assumed on structural grounds (Jones, 1981).

The red and grey essentially argillaceous beds at the base of the Singa Formation in the Langkawi Islands are of limited thickness. They give vertical facies changes to the dark carbonaceous siltstone lithology. However, the red and grey argillaceous facies is not observed in the basal part of the Singa Formation in the north of Perlis.

The top of the Singa Formation is defined in the Langkawi Islands by the conformably overlying base of the Chuping Limestone which is the late Lower Permian. Similarly and chronologically well-defined relationship exist in the north Perlis (Jones, 1981).

Thus, the Singa Formation age is determined by the relative dating of the known age of the overlying bed and also the underlying bed of the formation. The Singa Formation in Langkawi rests with apparent conformity on a bedded unit of red to pale mudstones with Devonian pelecypods and it is conformably overlain by the fossiliferous Permian limestone of the Chuping Formation (P. H. Stauffer & Nopadom Mantajit, 1981).

The Singa Formation cover about 30 square miles of the country in the mainland where the rocks are being disposed mainly about the east and westerly limbs of the Chuping syncline as shown in FIGURE 3 and FIGURE 4, after Jones (1981).

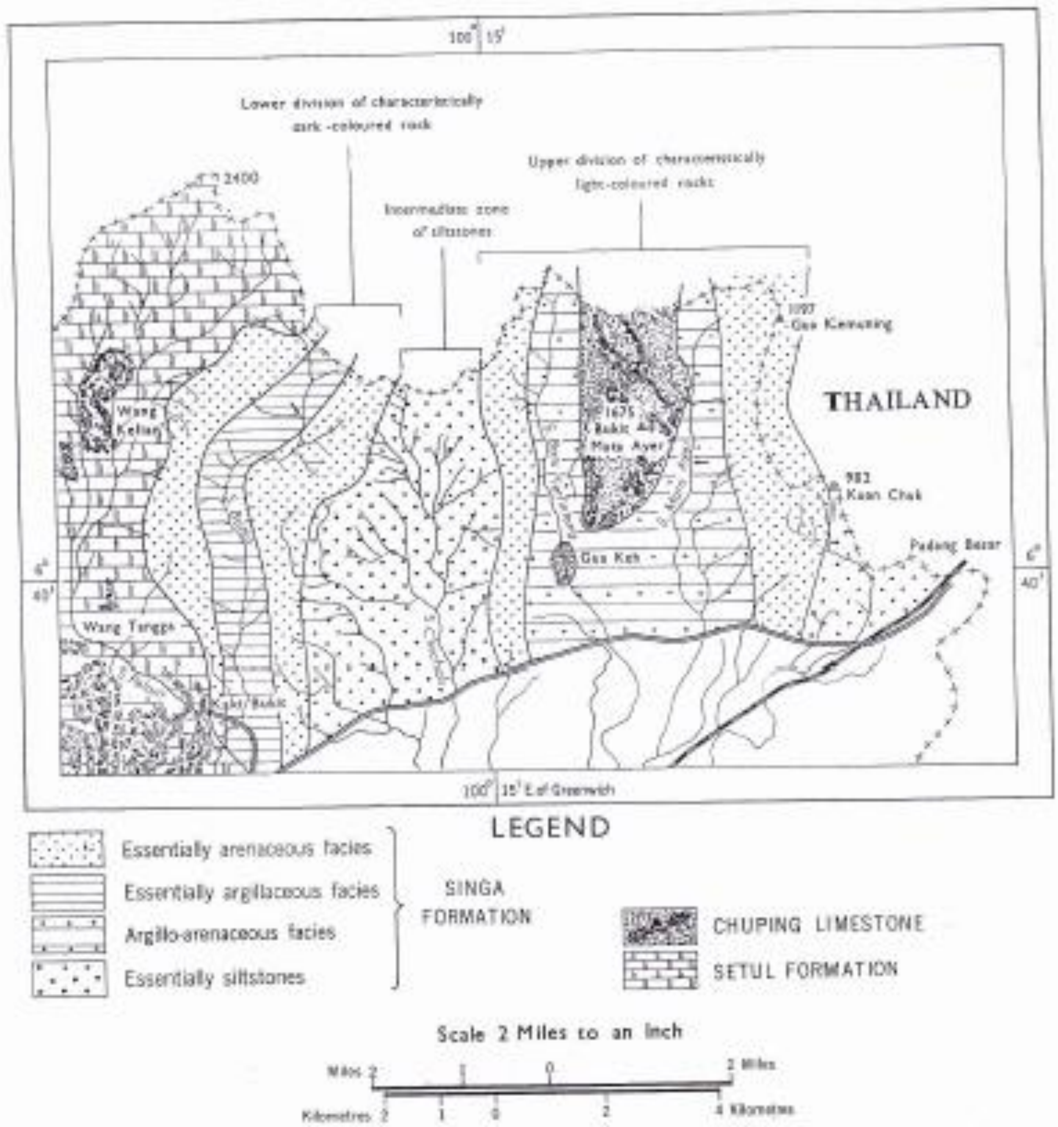


FIGURE 3: The approximate distribution of different facies of the Singa Formation in the North Perlis. (After Jones, 1981).

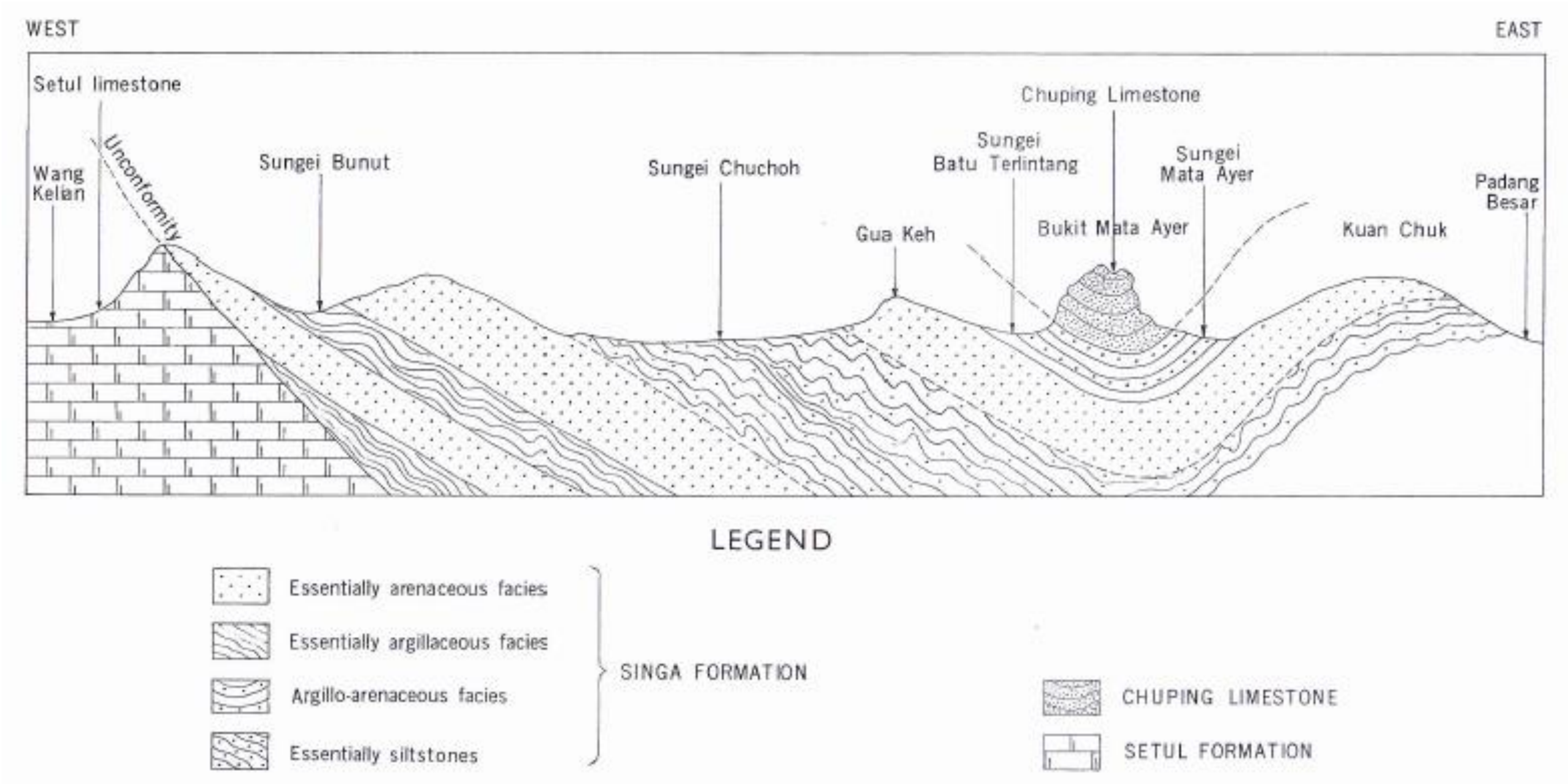


FIGURE 4: Cross section across North Perlis showing the structural distribution of the different facies of the Singa Formation. (After Jones, 1981).

In Langkawi Island, the Singa Formation covers an area of 40 square miles where the strata lying about the easterly dipping limb of the Machinchang Anticline (Jones, 1981). The Singa Formation in Langkawi Islands forms a vast area surrounding the east and south sides of the Gunung Raya. The outcrop extends to the southwest of Langkawi Island further to the Pulau Kentut and Pulau Singa where the strata dip gently eastwards. The base bed of Singa Formation form a small outcrop on Pulau Langgun in the northeast and Singa strata also build Pulau Kueh Besar to the north of Pulau Langgun (Jones, 1981). The Singa Formation in Langkawi Islands also include Pulau Tepor, Pulau Ular, Pulau Rebak, and Pulau Selang (Stauffer, P. H., & Lee, C. H., 1986; P. H. Stauffer & Nopadom Mantajit, 1981).

The rocks of Singa Formation consist of dark-grey or black wellbedded carbonaceous flagstones and siltstones with subordinate grey and brown immature quartzites and subgreywackes. Occasional greywacke and yellow sandstone also occurs. Dark-coloured silty mudstone is common in north Perlis whereas in Langkawi Islands the rock is similar but more fissile than in the north Perlis. In Pulau Langgun, brick-red basal, conglomeratic mudstone carrying well-rounded pebbles of quartzite and vein quartz occurs (Jones, 1981).

Jones (1981) describes the sedimentary features of the Singa Formation as follow:

- The main lithology in Singa Formation is the black carbonaceous siltstone sometimes containing appreciable calcite in the matrix. It often shows graded-bedding.
- Fucoidal impressions are prominent on the weathered surface of bedding-planes and cylindrical infillings disposed vertically to the bedding.
- Slumping and associated features can be seen in the coastal sections of the Singa Islands which suggest a steep submarine depositional slope.
- Well rounded boulders and pebbles of granite and quartzite occasionally been observed enclosed in the siltstone (probably slumped origin or dropstones).
- Beds of grey and brown subgreywacke and occasionally cleaner quartzite occur at well-spaced intervals.
- Thick beds of coarse-grained quartzite occurs in north Perlis.

- Thick prominent beds of yellow sandstone occur sporadically in the Singa and nearby islands. Those rocks are soft and muddy and contain only a minor proportion of poorly sorted quartz veins.

Stauffer and Mantajit (1981) divided the Singa Formation (1625m) into three members based on the tilloid-bearing unit. The measured sequence of Singa Formation in Langkawi is as follows:

1) Kentut member (1150m): Black mudstones, with megaclasts at several horizons, interbedded with subordinate sandstones.
2) Ular member (135m): Yellowish, laminated, fine sandstones and silty shales.
3) Selang member (340m): Black mudstones and shales with megaclasts at several horizons passing upwards into calcareous sandstones transitional to the Chuping Formation.

Stauffer and Lee (1986) identified the pebbly mudstones of Singa Formation in the Langkawi Island. These rocks have distinctive appearance in the field. They are crudely laminated to well bedded, dark grey, mainly fine-grained clastic rocks, containing megaclasts which occur singly or scattered through layers of a few meters thick, and locally displaying intense soft-sediment deformation. The characteristics of the presence of megaclasts strongly indicate the sequence is glacial marine deposits with ice-rafted stones.

Stauffer and Lee (1986) describes six lithofacies from measured sections within the Singa Formation on Pulau Tepor, Pulau Ular and Pulau Singa Besar in Langkawi. The six lithofacies are:

A. Laminated clean sandstone facies. Thick (0.5 – 2m) beds of fine to medium-grained moderately well sorted sandstone showing regular fine lamination, low-angle (hummocky?) cross-bedding, and sometimes soft-sediment deformation structures of 1+m scale.
B. Rhythmically interbedded sand-mud facies. Thin (1 cm±) beds of clean fine sand, commonly showing ripples and small-scale crosss bedding, and dark sandy mud. Character of interlayering approaches flaser bedding in places. Organic burrows common, and degree of bioturbation moderate.
C. Megaclasts-bearing rhythmically interlayered sand-mud facies. Differs from facies B in the less distinct interlayering, common presence of large (meter-

scale) soft-sediment structures ('slumping') and truncations suggestive of channeling, occasional occurrence of broken-up sandstone beds up to about 10cm thick, and presence of scattered megaclasts up to boulder size.

D. Sandy mudstones with thin graded sandstone facies. Dark poorly-sorted mudstone punctuated by thin (0.5-5cm) graded beds of fine sandstone (probable turbidites). Rare megaclasts to cobble size.
E. Diamictite facies. Unbedded, very poorly sorted dark clastic rock containing all sizes of clasts from clay and silt to large boulders in apparently random mixture.
F. Laminated sandstone-siltstone facies. Differs from facies C in weathering to a light yellowish-brown colour and soft, friable condition, and apparently in the greater variety of megaclasts, but shares with that facies the presence of rather large soft-sediment deformation structures and channel-like truncations of bedding.

Jantan (1973) divided the Singa Formation into 4 members namely the Rebak, Kentut, Ular and Selang which occurring in the southwestern part of Langkawi Island. In his thesis mention that Singa Formation dominantly consist of carbonaceous shale, mudstone or phyllite, pebbly mudstone and interbedded of sandstone. TABLE 1 summarised the members of Singa Formation according to Jantan (1973).

TABLE 1: Summary of subdivision of Singa Formation (After Jantan, 1973)

Member	Description
Selang (226m)	Consists of a basal black mudstone, in part containing pebble clasts, grading upwards into interbeds of thick black mudstone and sandstone and then predominantly black or brown mudstone and sandstone. This member covers the southernmost tip of Pulau Ular, Pulau Selang, Pulau Lalang and Pulau Singa Kechil with Pulau Singa Besar the lateral equivalent sections from all the four islands together. It can be divided into 4 subunits (refer to Ahmad Jantan)
Ular (130m)	The uppermost part of the member is argillaceous and grade into the black shale of the Selang member. The complete section of this member can be seen in Pulau Ular. This member underlies the whole of Pulau Ular except for the southernmost tip, Pulau Tak Berumput, Tanjung Bewak, Teluk Air Kaca, Teluk Hantu, Teluk Boton, Tanjung Boton of Pulau Singa Besar. It can be divided into 7 subunits (refer to Ahmad Jantan)
Kentut (1200m)	This member underlies Pulau Tepor, Pulau Kentut Besar, Pulau Kentut Kechil, Pulau Beras Basah, and the southwestern part of Pulau Langkawi with exposures extending from Tanjung Sawa to Teluk Temoyong and the southern half of Pulau Singa Besar. It consists black mudstone and shale, in parts interrelated with sandstone laminae, lenses and bands. It can be divided into 4 subunits.
Rebak (500m)	Thick sequence exposed at the south bay of Pulau Rebak Besar, Pulau Selat Senari and Pulau Rebak Kechil. Consists mostly of mudstones, both red and grey, shale, siltstone and interbedded sandstone. This member underlies Pulau Rebak, covering part of Pulau Rebak Besar and the whole of Pulau Selat Senari and Pulau Rebak Kechil. The basal section was found in Pulau Langgun. A narrow strip of red and grey mudstone at Pulau Tuba could be part of this member.

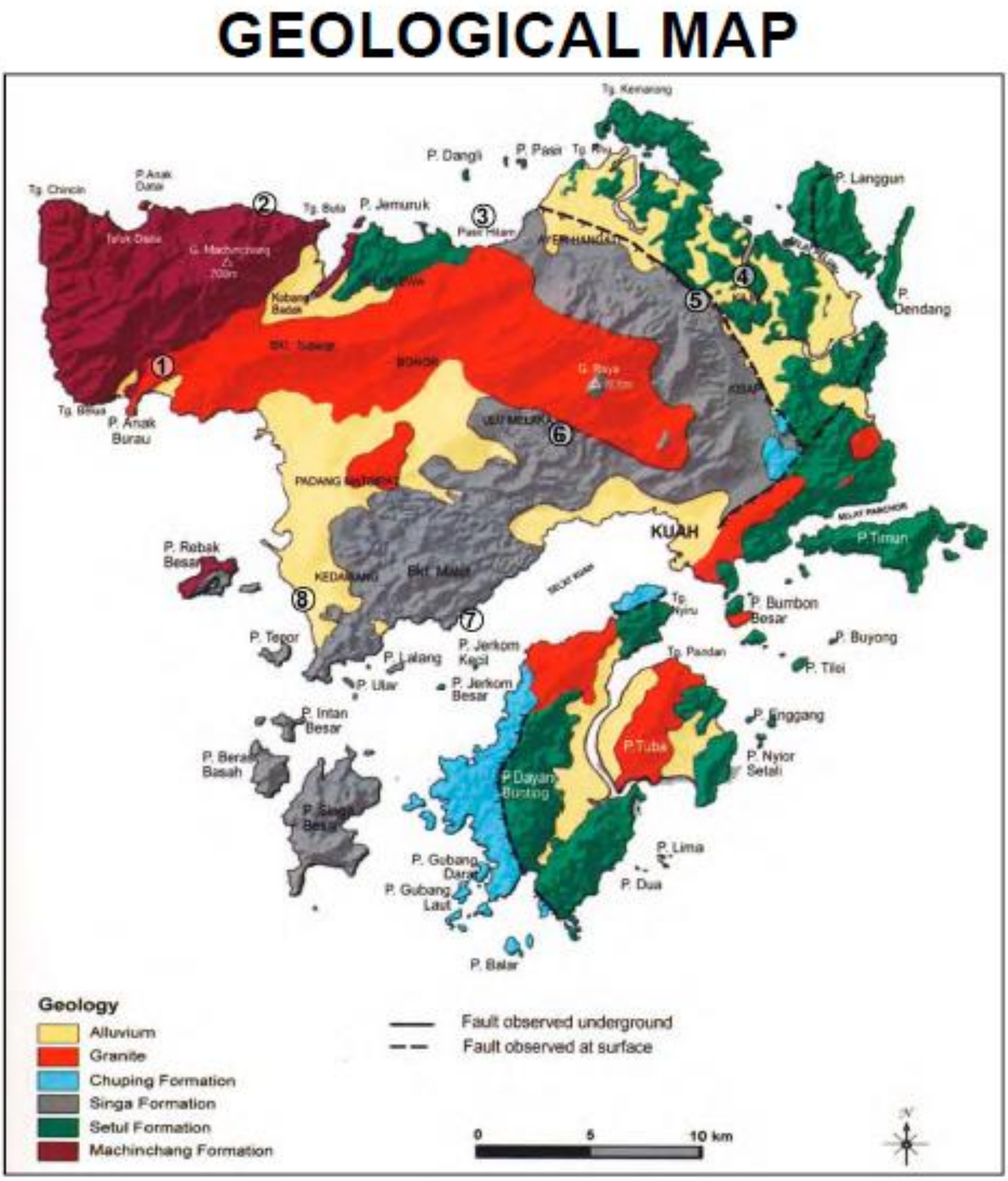
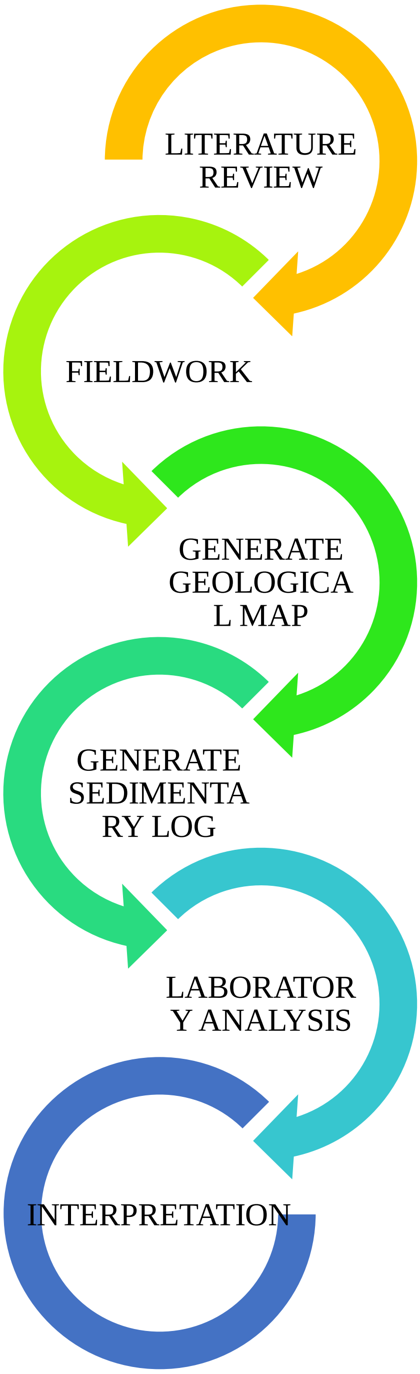


FIGURE 5: Geological map of Langkawi Island (modified after Jones, 1981)

CHAPTER 3

METHODOLOGY



3.1. LITERATURE REVIEW

Literature review is done in order to have a better understanding of the geology of the area. Literature review from previous research provides the general understanding on the Singa Formation sedimentology as well as the stratigraphic units from different author views.

3.2. FIELDWORK

Fieldtrip to the study area will be conducted for data and sample collection. Structural data such as fault, fold and bedding at the site will be observed. The dip and strike reading is taken as the data to construct geological map of the study area. A sedimentology log of the outcrop of the study area is constructed with the recognition of different facies at the outcrop. Samples from the outcrop are taken for thin section analysis in order to determine the mineral in the rock, thus can contribute in the sedimentary facies analysis. The facies analysis comprises a three step work flow which are description, classification and interpretation.

The study area are located at the road side of Teluk Chek Dendang, Tanjung Mali and Tanjung Malai, Langkawi Islands.

3.3. CONSTRUCT GEOLOGICAL MAP

Geological map along the transect area is constructed to determine the lithology boundary of the formation. The geological map illustrate the general geology of the Langkawi Islands. The geological map is constructed mainly based on the information gained during the fieldwork. It requires several outcrop of the same lithofacies in order to create a transect map.

3.4. SEDIMENTOLOGY LOG

Sedimentology log on the exposed outcrop is constructed to determine facies association and consequently the facies succession of the exposed outcrop of study area. By quicklook interpretation of the sedimentology log and detailed description of the facies, the process of sediments transport could be determined.

3.5. LABORATORY ANALYSIS

Petrographic analysis which is the thin section analysis is done by study the mineralogical composition of the samples under the transmitted light microscope. Thin section analysis is completed for further information of the sedimentary facies of the samples. This analysis can be a good evidence for the interpretation of the sedimentary environment of the study area.

Geochemical analysis that are selected for this project are X-Ray fluorescence (XRF) and X-ray diffraction (XRD).

3.6. INTERPRETATION

Interpretation of the sedimentary process involve in the building of the sedimentary facies is based on the sedimentology log of the outcrop. Detailed description of the sedimentary facies and sedimentary structures gives an idea on the processes acted to the sediments and caused how the sediments was deposited. The main result for this project is to interpret the depositional environment of the study area.

CHAPTER 4

KEY MILESTONE & GANT CHART

4.1. KEY MILESTONE

- Fieldwork
  - Data and sample collection
  - Construct sedimentology log
- Facies analysis
  - Describe the facies of the study area
  - Determine the facies association
- Laboratory analysis
  - Petrography
  - Geochemistry

4.2. GANT CHART

TABLE 2: Gant Chart for Semester 1 (FYP 1)

Activities	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Tittle													
Confirmation of Project Tittle													
Preliminary Research Work													
Project Work Continues													
Fieldtrip													
Mapping and Facies analysis													

TABLE 3: Gant Chart for Semester 2 (FYP 2)

Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Laboratory Analysis														
Project Work Continues														
Report Writing														

CHAPTER 5

RESULT AND DISCUSSION

5.1. FIELDWORK

5.1.1. Traverse Map

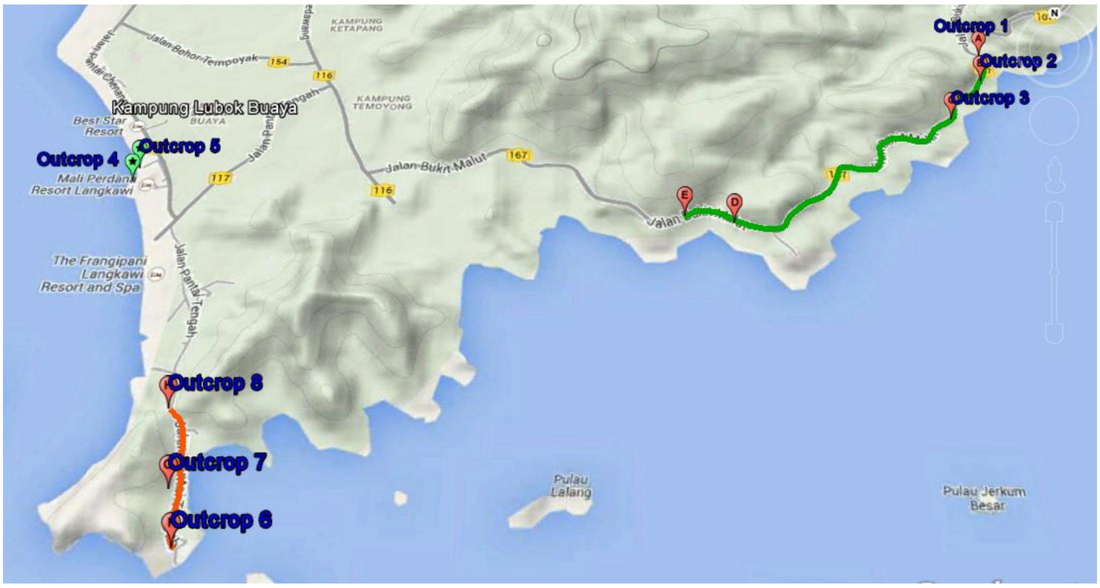


FIGURE 6: Road traversing of the Singa Formation at Southwestern part of the Langkawi Island.

TABLE 4: Coordinate of Road Traversing 1 (Green)

Checkpoint	Coordinate
A	6°17'55.26"N , 99°47'19.26"E
B	6°17'46.20"N , 99°47'17.76"E
C	6°17'32.94"N , 99°47'7.32"E
D	6°16'59.04"N , 99°46'7.92"E
E	6°17'1.26"N , 99°45'56.10"E

TABLE 5: Coordinate of Road Traversing 2 (Orange)

Checkpoint	Coordinate
F	6°15'38.40"N , 99°44'7.62"E
G	6°15'50.46"N , 99°44'4.74"E
H	6°16'8.40"N , 99°44'1.26"E

5.1.2. Teluk Chek Dendang

There are 3 exposed outcrop in this area that accessible for the fieldwork.

The first outcrop (Outcrop 1) is located at the GPS location of N 6 17.921 E 99 47.321. The outcrop exposure is about 6 – 8 meters wide and 5 meters thick along the road side. Three samples were collected which labelled as S10, S11, and S12.

The second outcrop (Outcrop 2) is located at the GPS location of N 6 17.770 E 99 47.296. The outcrop exposure is about 15 – 20 meters wide along the road side. The total thickness of the exposed outcrop is about 11 meters. This rock exhibit a general bedding strike that fall within the range of 20° - 35° and show dip angle around 20° - 25° towards South East. Three samples were collected and labelled as S1, S2, and S3.

The third outcrop (Outcrop 3) is located at the GPS location of N 6 17.549 E 99 47.122. The outcrop exposure is about 20 meters wide and 10 meters thick along the corner of the road side. One sample were collected, labelled as S13.

Sedimentology log was constructed at the first and second location.

In general, the colour of the outcrop is black to dark-grey mudstone. However, in the third outcrop, the outcrop is mostly brownish in colour. This may be caused by the weathering of iron (Fe).

There are 5 facies recognized in the first two outcrop and only one facies is recognized in the third outcrop.

The facies are:

1. Massive siltstone facies (F1)
2. Finely laminated siltstone facies (F2)
3. Thick laminated mudstone facies (F3)
4. Finely laminated mudstone facies (F4)
5. Black mudstone facies (F5)

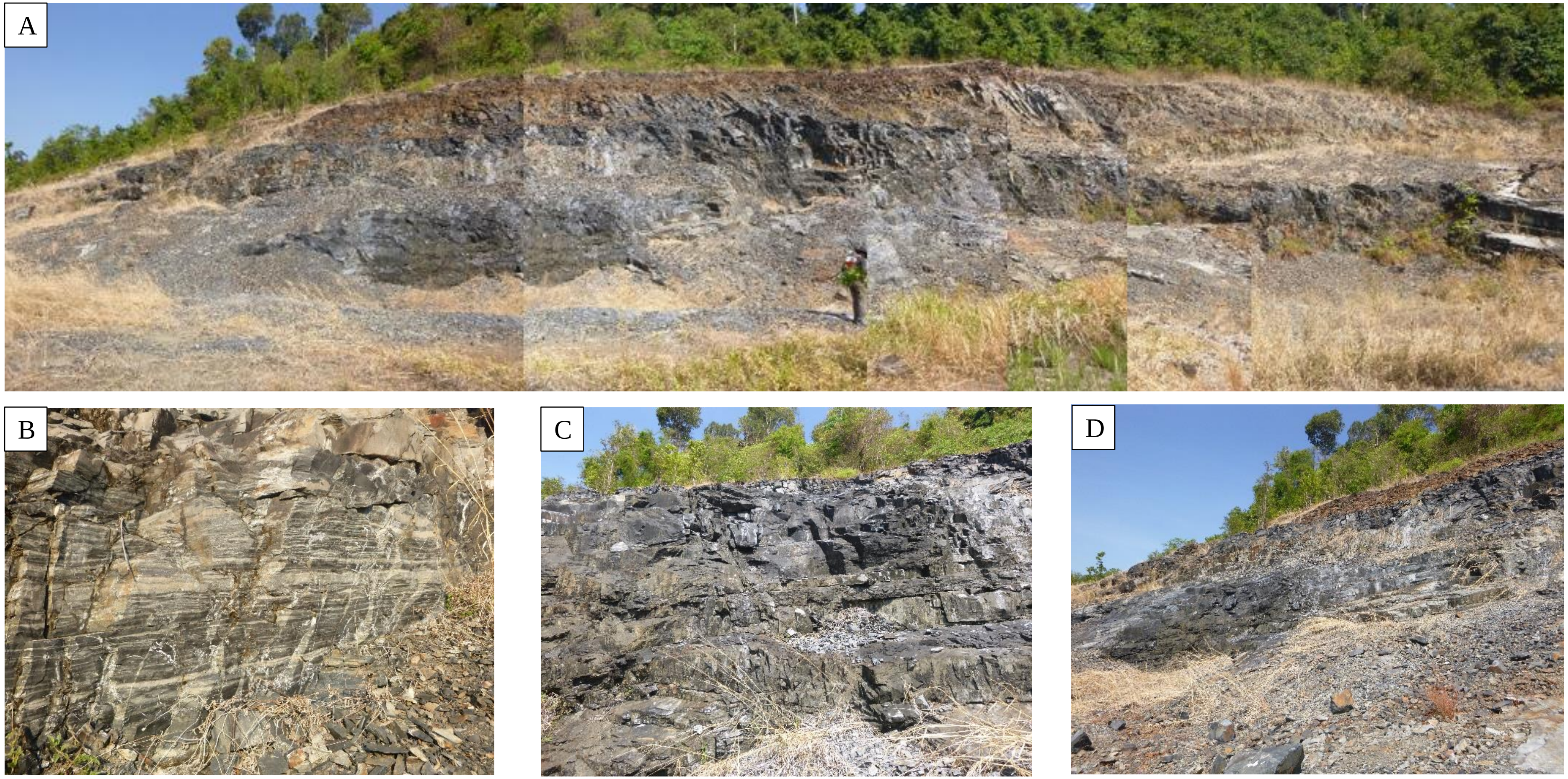


FIGURE 7: (A) Landscape view of Outcrop 2. (B) Rock showing finely laminated mudstone facies. (C) Rock showing black mudstone facies. (D) Dipping of the rock towards South East.

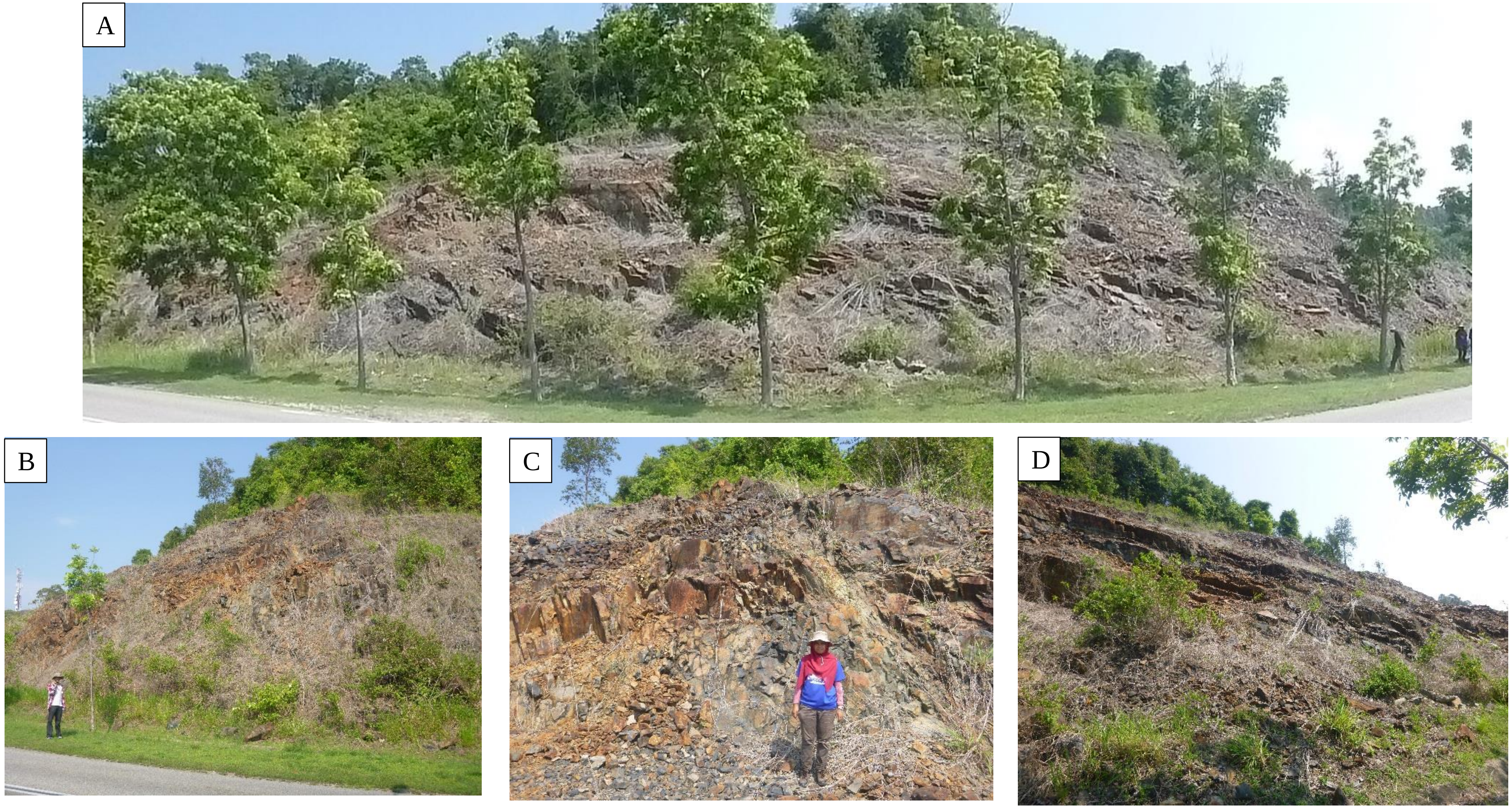


FIGURE 8: (A) Landscape view of Outcrop 3. (B) Outcrop at the corner of the roadside. (C) Rocks of the top part of the outcrop displaying brownish colour due to weathering. (D) Dipping of the rock towards South East.

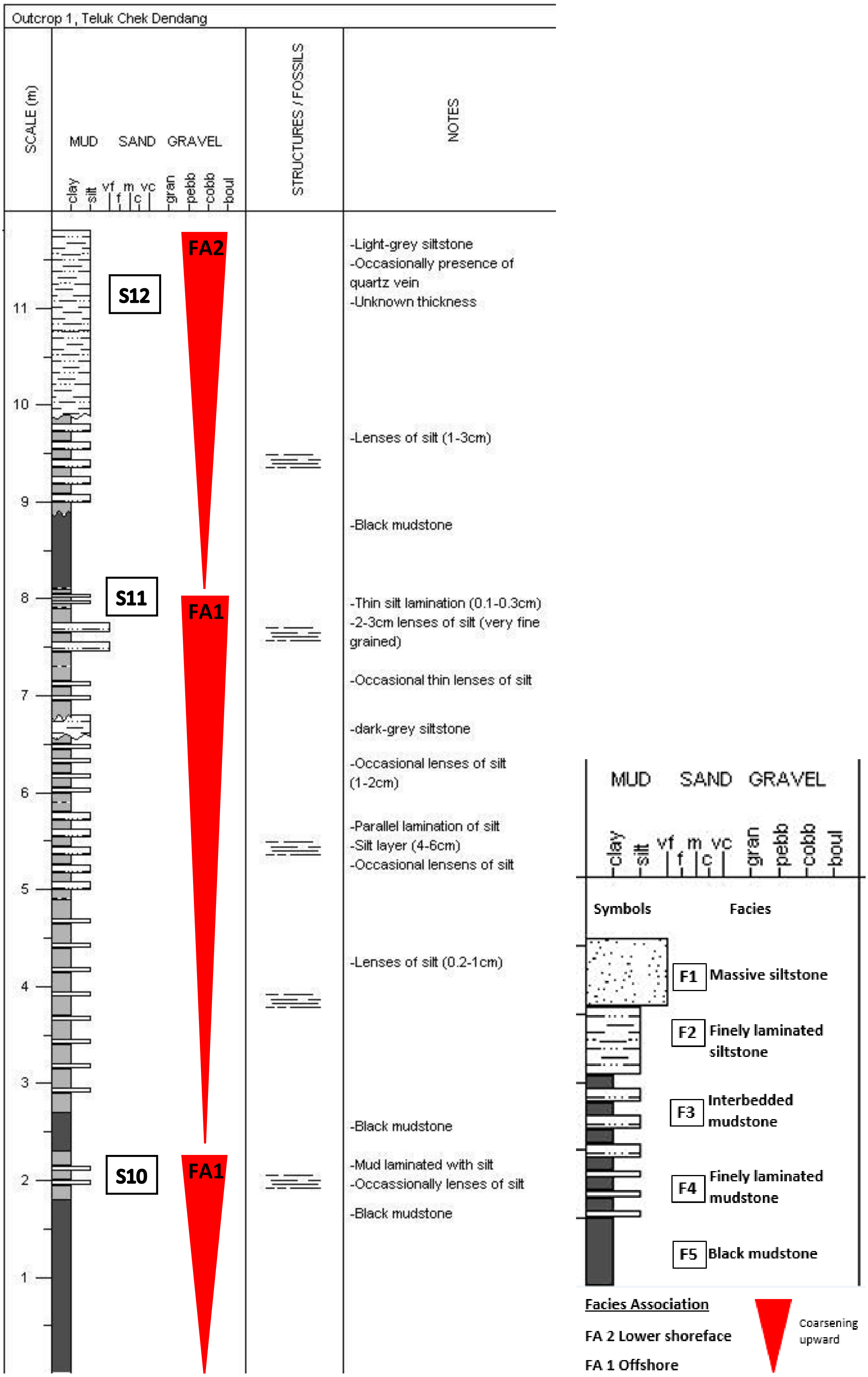


FIGURE 9: Sedimentology log of Singa Formation at outcrop 1, Teluk Chek Dendang. The succession was characterised by several coarsening upward sequences. (Scale 1:50cm)

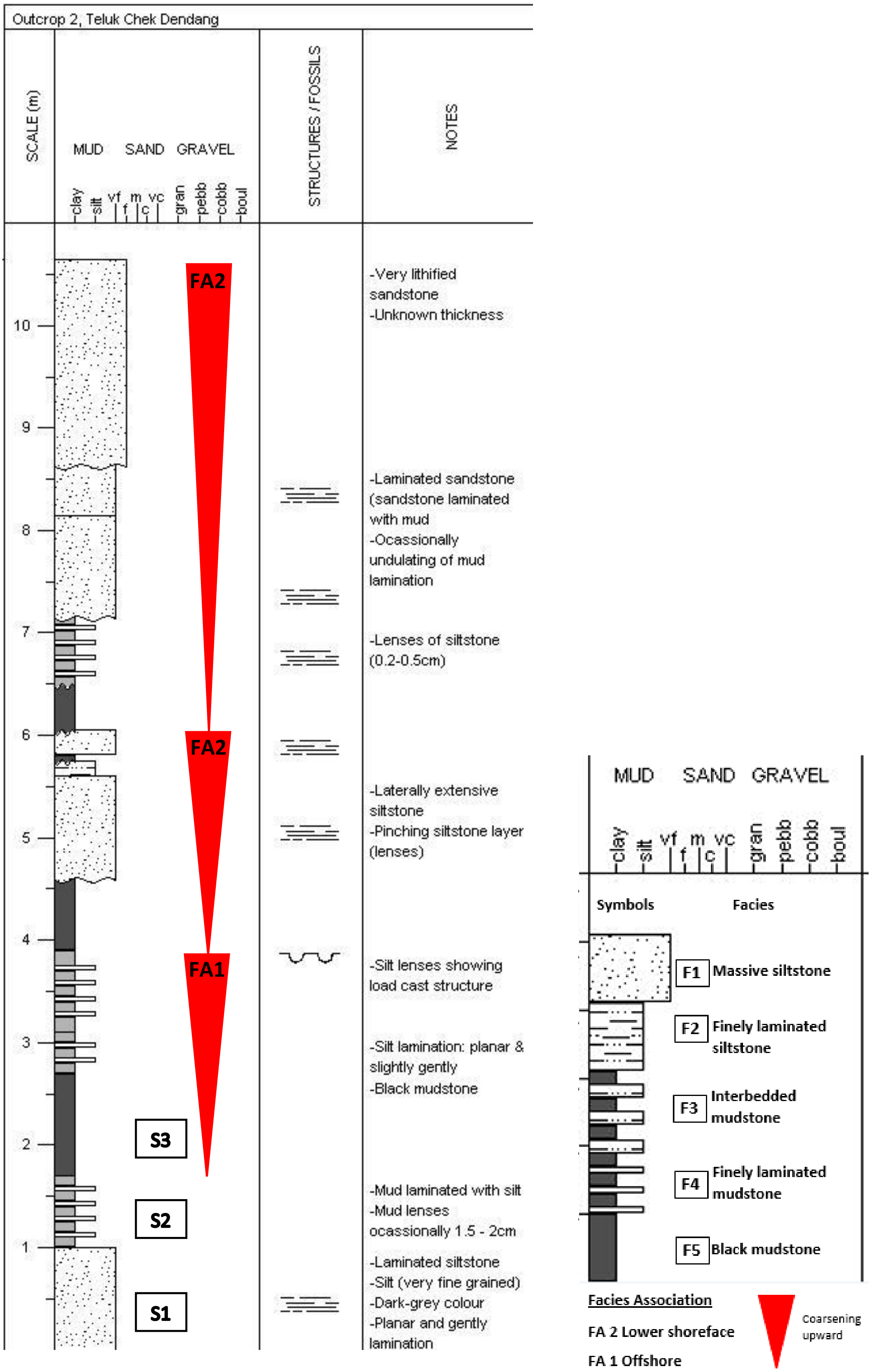


FIGURE 10: Sedimentology log of the Singa Formation at outcrop 2, Teluk Chek Dendang. The succession was characterized by several coarsening upward sequences. (Scale is 1:50cm)

5.1.3. Tanjung Mali

The significance of Singa Formation compared to other formation is the occurrences of dropstone. Two outcrops at Tanjung Mali show the evidence of the dropstone occurrence.

The first outcrop (Outcrop 4) is located at the GPS location of N 6° 17.186 and E 99° 43.645. In this outcrop, the occurrences of dropstone are more frequent and the size of the dropstone is much bigger compared to the other outcrop.

The second outcrop (Outcrop 5) is located at the GPS location of N 6° 17.257 and E 99° 43.659. The exposure of this outcrop is limited due to human invasion and only small portion of the outcrop is left behind.

FIGURE 11: Outcrop 4 that consist of dropstone occurrences at Tanjung Mali.

These two outcrop is a typical black mudstone of the Singa Formation with some silty layers (FIGURE 12(A) and FIGURE 13(A)). The structure at the base of the outcrop display as interbedded of mudstone with silt. Occasionally the silt layers display lenses structure. This location of Singa Formation contains dropstone or diamictites (FIGURE 12(B) and FIGURE 13(B)). The size of the dropstone found at Tanjung Mali ranging from 1cm to 4cm.

This outcrop is a fine grain rock which deposited in almost stagnant water. This is because clay particles only settle down when there is no flow or almost no flow. This indicates that the depositional environment is very far away from the land areas such as big lake or deep sea. Dropstones are the pieces of rock that have been drop into fine grain sediment.

There are two theories on the origin of the dropstone. First is the theory of root of continental plant that carry pebbles or larger sediments. As the root went further to the sea, it decay and causing the pebbles to drop into the fine sediments at the deep sea. Second is the theory of ice berg. Ice berg is from the broken glacial. As it moves from the mountain, along the way they had been dug into rocks and take a lot of rocks into the ice. When the ice berg broke away from the glacial at the coast line, they will float into the middle of the ocean carry with then with a lot of pebbles. As the ice berg melts, the pebbles will drop to the bottom of the ocean.

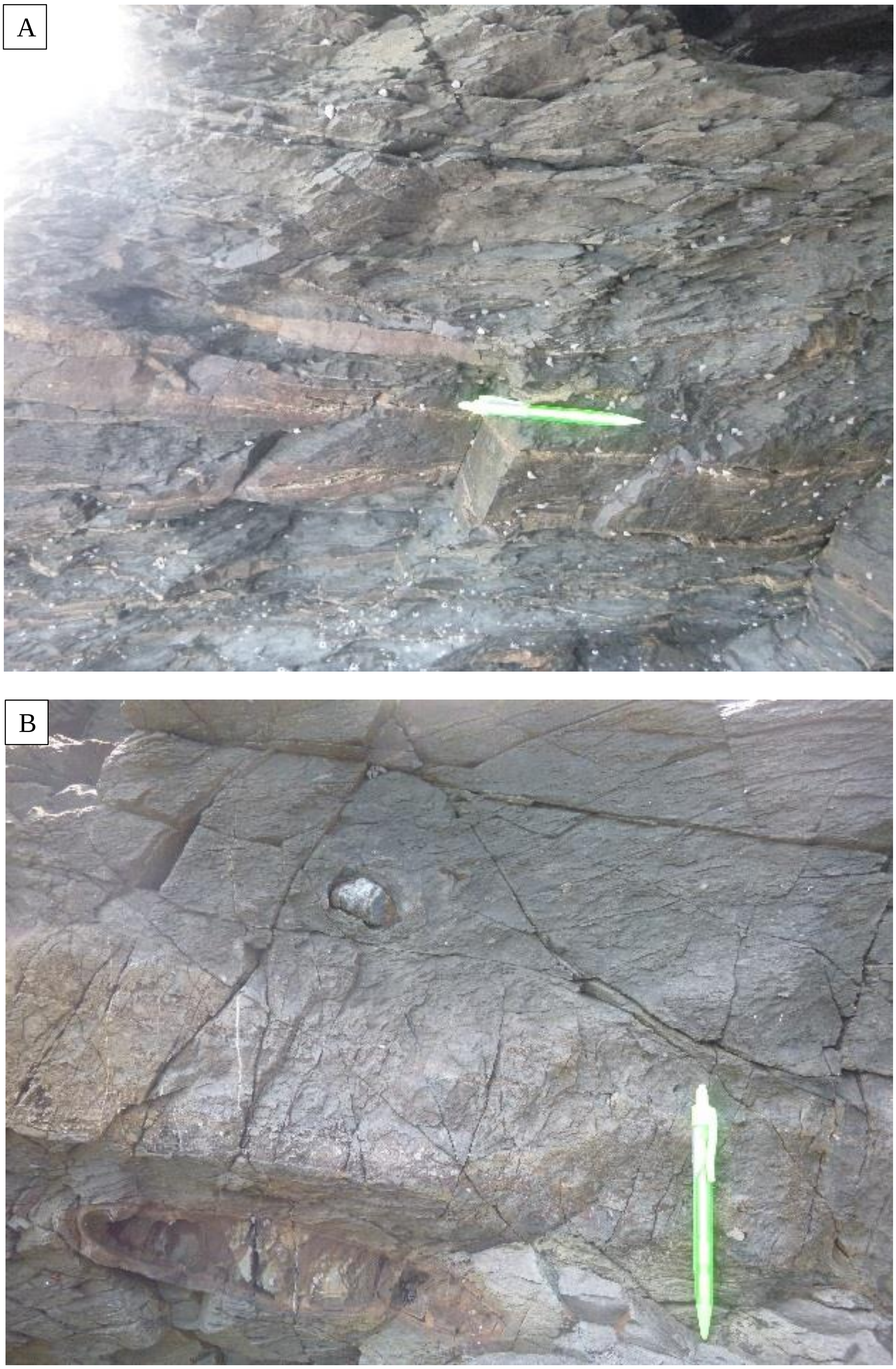


FIGURE 12: (A) Interbedded mudstone with siltstone and (B) dropstone of the Singa Formation at outcrop 4. Pencil is 15cm long.

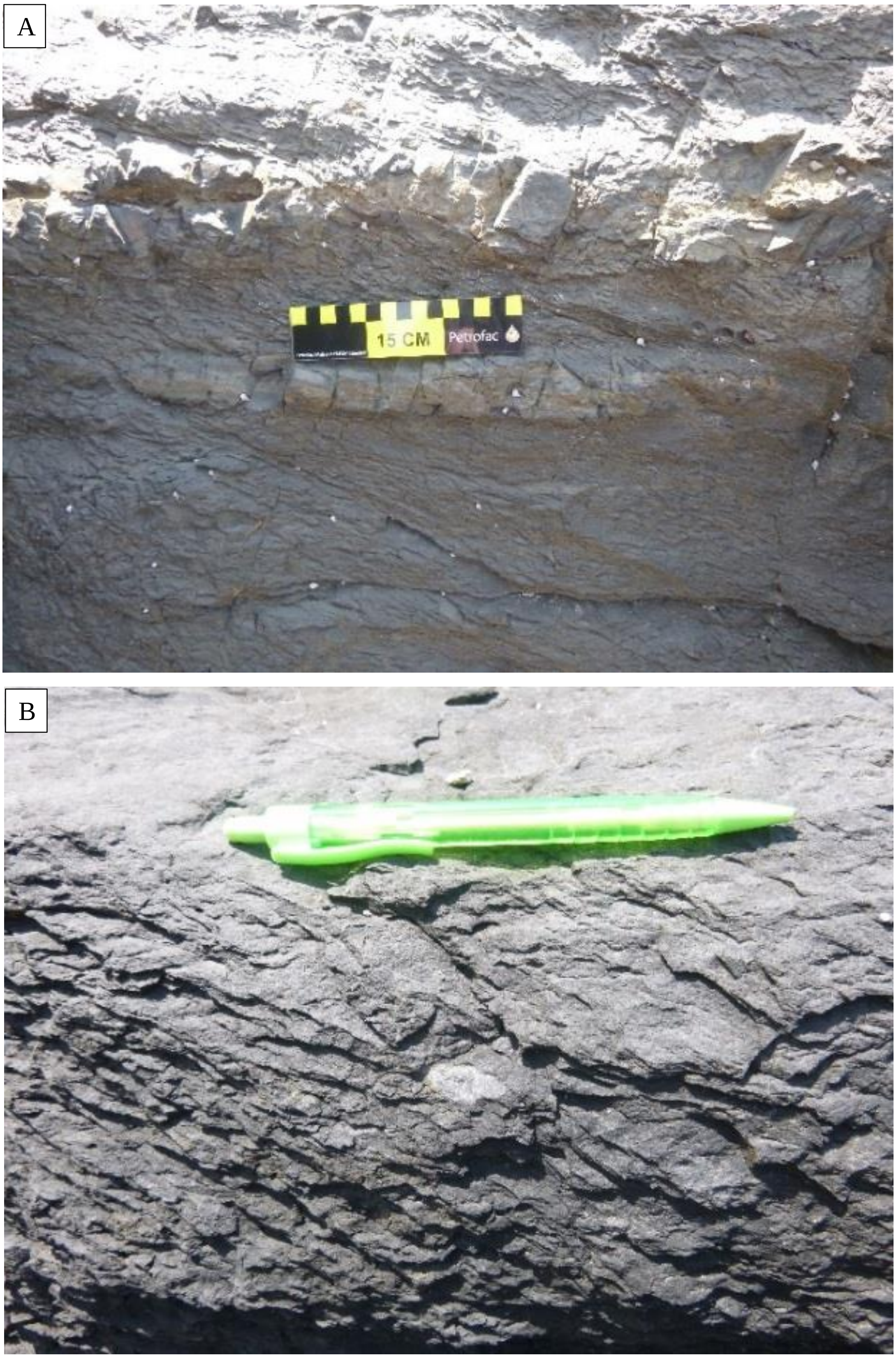


FIGURE 13: (A) Mudstone with silt layers and (B) dropstone of Singa Formation at outcrop 5. Pencil is 15cm long.

5.1.4. Tanjung Malai

There are 3 outcrop exposed around Tanjung Malai area.

The first outcrop (Outcrop 6) is located at the GPS location of N 6 15.640 and E 99 44.127. The exposure of this outcrop is quite limited as it was covered with a lot of vegetation, about 3 meters thick. One sample is collected from the outcrop and labelled as S17.

The second outcrop (Outcrop 7) is located at the GPS location of N 6 15.841 and E 99 44.079. The exposure of this outcrop is about 8 meters wide and 3 meters thick. One sample is collected from the outcrop which labelled as S16.

Based on the colour of both of the outcrop, it is likely to be the Singa Formation. The colour of the outcrop is dark-grey to black in colour. In general the outcrop exhibits mudstone characteristics. It also display parallel lamination. However, the rock in this outcrop is more fissile compared to the other previous outcrop where it breaks along the bedding plane easily.

The fissility of this rock is possessed by shale. Fissility is the ability of mudrock to split along smooth plane parallel to the stratification. The main factor for the property is due to the compaction-induced alignment of clay minerals and also with the presence of lamination. The fissility of these outcrops compared to the previous outcrop is probably due to the absence of the other types of minerals that could give random fabric to the mudrock which could retained on compaction. The degree of fissility shown by mudrocks may be related to weathering at the outcrop.

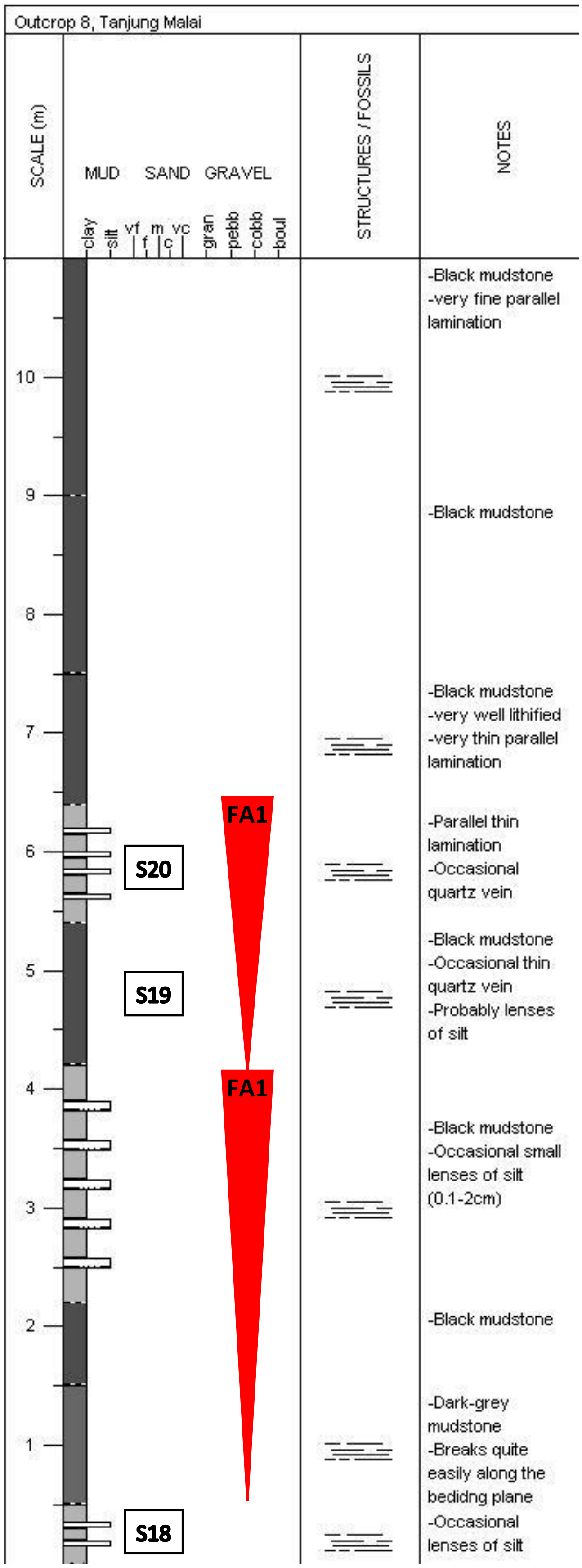
FIGURE 14: Fissile mudstone (shale) at Outcrop 6. (A) Outcrop exposure at Tanjung Malai. (B) Closer view of the shale.

FIGURE 15: Fissile mudstone at outcrop 7.

The third outcrop at this area is located at GPS location of N 6 16.140 and E 99 44.021. The outcrop exposure is about 15 meters wide and 3 meters thick along the road side. Generally the outcrop is a black mudstone. Three outcrop were collected at this outcrop and labelled as S18, S19 and S20. However, when observe carefully, there are 2 facies recognised in this outcrop. The facies are:

1. Finely laminated mudstone facies (F4)
2. Black mudstone facies (F5)

FIGURE 16: (A) Black mudstone facies at outcrop 8. (B) Finely laminated mudstone facies at outcrop 8. (C) Landscape view of the outcrop 8 at Tanjung Malai.



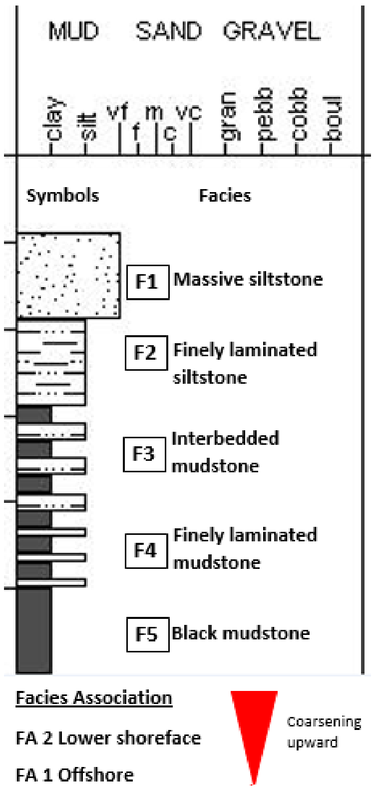


FIGURE 17: Sedimentology log of Singa Formation at outcrop 8, Tanjung Malai. The succession was characterized by several coarsening upward sequences. (Scale is 1:50cm)

5.1.5. Lithology Map

FIGURE 18: Lithology map of southwestern of Langkawi Island. Singa Formation is indicated by green colour which covers the study area.

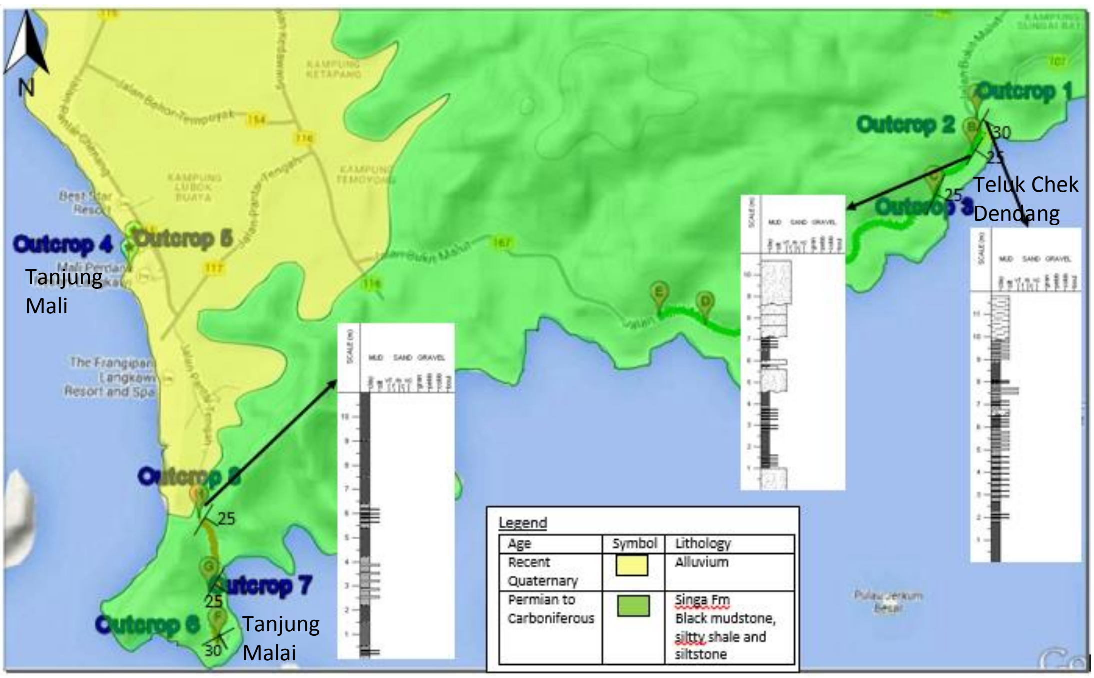


FIGURE 19: Lithology map of southwestern of Langkawi Island with sedimentary log constructed at the study area. The sedimentary logs were characterized by several coarsening upward sequences.

5.2. FACIES ANALYSIS

5.2.1. Massive Siltstone Facies (F1)

The massive siltstone facies commonly forms cm-thick beds of fine to very fine grained sands with no distinct sedimentary structures. This massive sandstone facies are very well lithified. The colour of this facies is dark-grey.

FIGURE 20: Hand specimen of massive siltstone at outcrop 1 (A) and outcrop 2 (B).

Interpretation: The structureless siltstone indicate that the flow is more competent. The competent flow cause the sediments unable to form any bedding or lamination structures. The flow carries the sediments and lump the sediments when the energy flow are unable to carry the sediments any longer. Thus, it may indicate that the environment of deposition is more proximal which in areas nearer the shore.

5.2.2. Finely Laminated Siltstone Facies (F2)

Finely laminated sandstone is composed of very fine rained silt of dark-grey colour. This facies contain planar and gently undulating lamination. The thickness of this facies as about 50 to 100cm. The sandstone is very well lithified. Within this facies, occasionally cross-lamination occurs.

FIGURE 21: Rock sample of finely laminated siltstone at outcrop 2. Note the cross lamination of the siltstone.

Interpretation: This facies indicate that some kind of flow is introduced. The cross-laminated sandstone facies represent the oscillatory flow and/or combined flow storm deposition. The very fine sediments were carried by some sort of energy flow that resulted in the gently undulating lamination and cross-lamination of siltstone indicating unidirectional currents. Thus, the sediments deposited in environment with energy flow that able to carry the sediments.

5.2.3. Thick Laminated Mudstone Facies (F3)

The structure of interbedded mudstone facies is the same as the finely laminated mudstone facies. The different is in the thickness of the siltstone layer. The silt layer ranging from 4 – 6cm thick. The thickness of the silt is not equal throughout the layer. Occasionally, the mudstone show flame structure and load cast structure. The silt layer also display load cast structure.

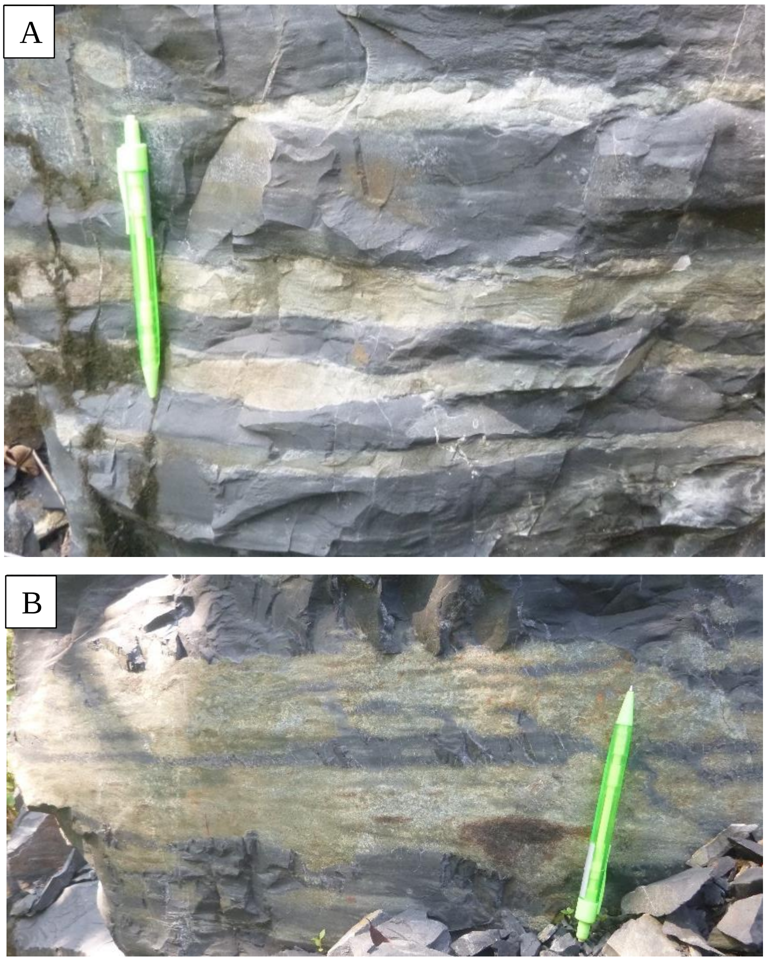


FIGURE 22: (A) Interbedded mudstone with siltstone at outcrop 2. (B) Flame structure observed at Outcrop 2.

Interpretation: The thickness of the silt layers compared to the finely laminated mudstone facies indicate that the introduction of silt into the mudstone layer is stronger and longer compared to the previous facies. It might be representing a longer intervals of wave, current and/or storm deposition. The flame structure is formed when the weight of an overlying bed (silt) forces an underlying bed to push up through the overlying bed. Thus, the overlying bed is higher density than the underlying bed.

5.2.4. Finely Laminated Mudstone Facies (F4)

Finely laminated mudstone facies composed of laminated, cm-thick mudstone and very fine to fine grained siltstone. The colour of the mudstone is black and the siltstone is dark-grey in colour. The thickness of the silt layer ranging from 0.1 to 3cm. Within the silt layer, it shows lamination which difficult to distinguish in the hand specimen. It only can be seen in polished sample. The lamination of siltstone sometimes displaying ripple like structure. Occasionally, the siltstone display load cast structure. The siltstone bed also displaying planar and undulating lamination.

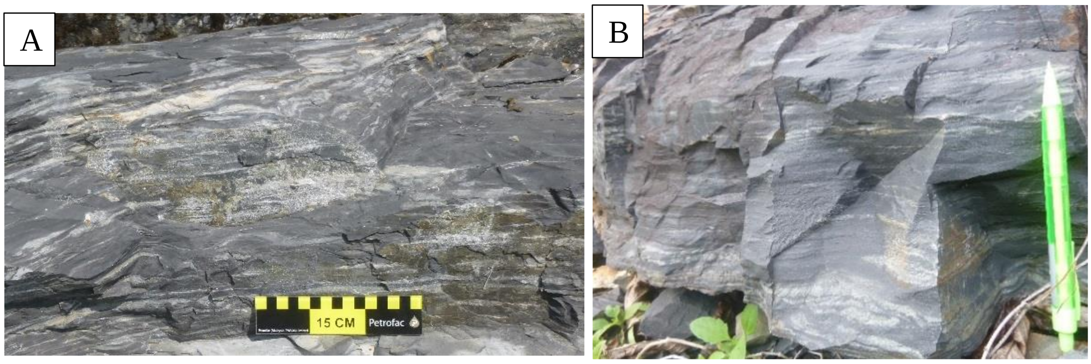


FIGURE 23. (A) Finely laminated mudstone with siltstone in outcrop 1 and (B) finely laminated mudstone with siltstone in outcrop 2.

Interpretation: Within a background of mud sedimentation, weak flow of silt was introduced to the environment. This facies is interpreted as representing of a depositional environment of away from energy effect but there are times where small pulses of tail sand or silt is introduced. It might be representing intervals of wave, current and/or storm deposition separated by slackwater intervals. Period of storm activity resulted in increase in wave energy and sediments was introduces into the muddy environment. The load cast structure is form when the silt which is denser than the mud is introduced to the mud where the mud is still soggy causing the silt to sink deeper in the mud.

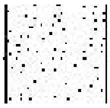
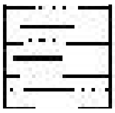
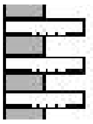
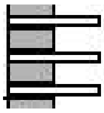
5.2.5. Black Mudstone Facies (F5)

Black mudstone facies comprises of cm to m thick black mudstone. This mudstone facies are very well lithified which indicate that this facies had underwent intense compaction and cementation. The mudstone facies are dominantly consists of clay particles since there is no grains observed. The facies surface feels like ‘talcum powder’ when touch by hand. No sedimentary structures were observed in this facies and palaeocurrent data could not be obtained.

FIGURE 24: (A) Hand specimen of black mudstone facies at outcrop 2. (B) Black mudstone at outcrop 1. (C) Black mudstone at outcrop 3.

Interpretation: This black mudstone facies is interpreted as representing of quiet water deposition from suspension. This facies is deposited in almost stagnant water. The clay particles only settle down when there is no flow or almost no flow. The clay was building up very slowly by fallout from suspension. Thus, this suggest that the depositional environment for this facies is unaffected by strong water movements. It may be classified as offshore deposits.

TABLE 6: Summary of the characteristics and interpretation of five (5) facies identified in the Singa Formation at Teluk Chek Dendang, Langkawi.

Facies	Lithofacies	Process	Interpretation
Massive siltstone  (F1)	Massive fine to very fine grained silt	More competent flow	Depositional environment is more proximal to land area
Finely laminated siltstone  (F2)	Parallel & gently undulating laminated siltstone	Flow is introduced	Deposited in low energy current/ wave transport
Interbedded mudstone  (F3)	- Mud laminated with silt - Silt layer ranging from 4-6cm thick	Suspension of clay particles followed by subsequent of stronger and longer energy event	The silt bed represent a longer interval of wave, current &/ storm deposition
Finely laminated mudstone  (F4)	- Mud laminated with silt -Silt lamination are parallel & slightly gentle	Suspension of clay particles followed by subsequent higher energy event	There is occasional of wave/current energy to the calm environment
Black mudstone  (F5)	- Black mudstone - No grains observed - No sedimentary structure observed	Clay particles deposited where there is no flow/ almost no flow	- Depositional environment unaffected by strong water movement - Offshore deposits

5.3. LABORATORY ANALYSIS

5.3.1. Petrography (Thin Section) Result

Outcrop 1 (Teluk Chek Dendang)

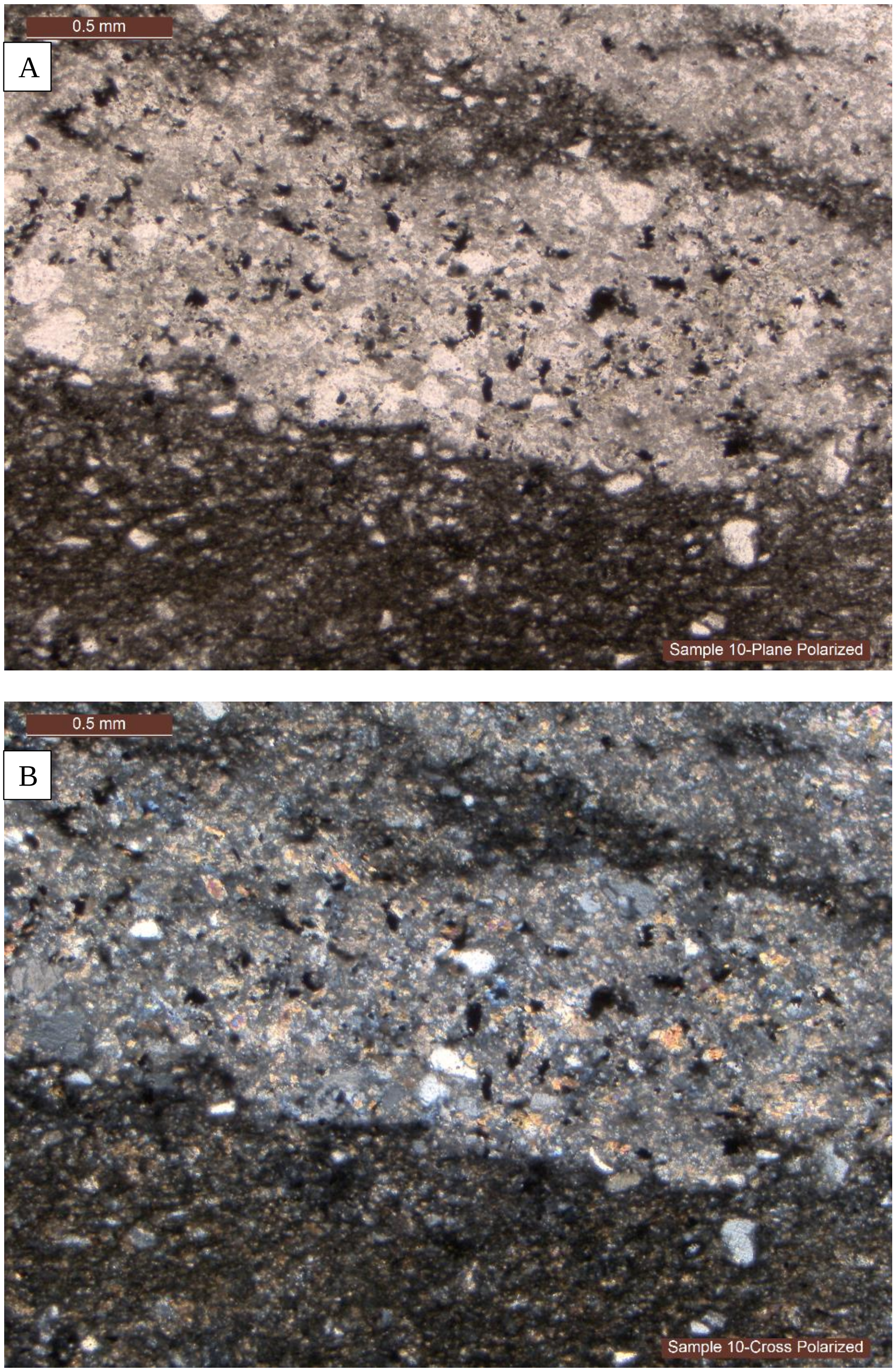


FIGURE 25: S10 of F4. (A) Plane polarized light. (B) Cross polarized light. Angular quartz grains of silt (top) laminated with mudstone (bottom). Presence of Hematite, opaque mineral. Muscovite shows orange colour. Muscovite is common mineral in mudstone.

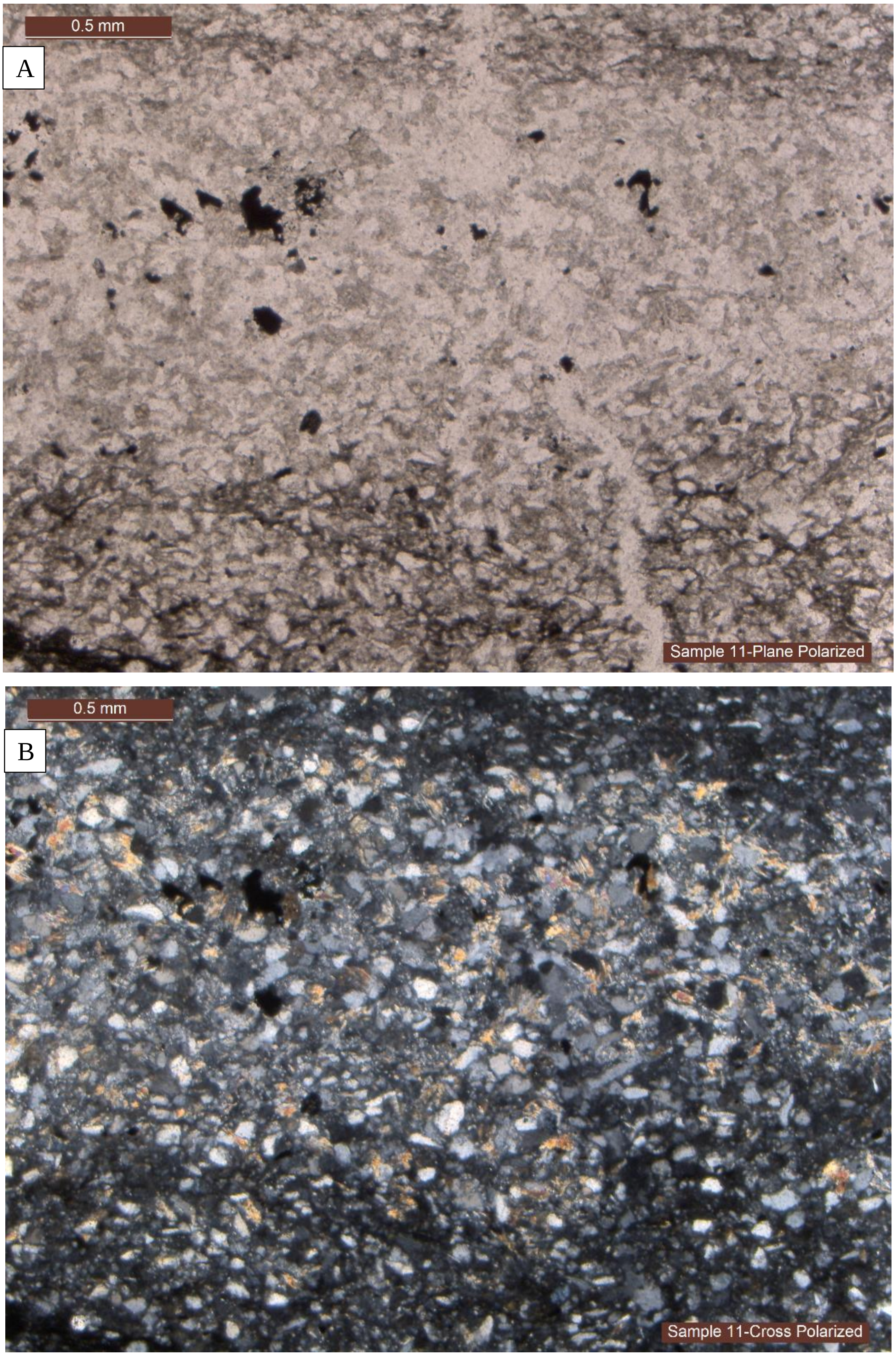


FIGURE 26: S11 of F4. (A) Plane polarized light (B) Cross polarized light. Lamination in mudstone. Consists of alternations of siltstone and clay mineral. Represent the seasonal deposition. Note: coarsening upward sequence from clay minerals to siltstone.

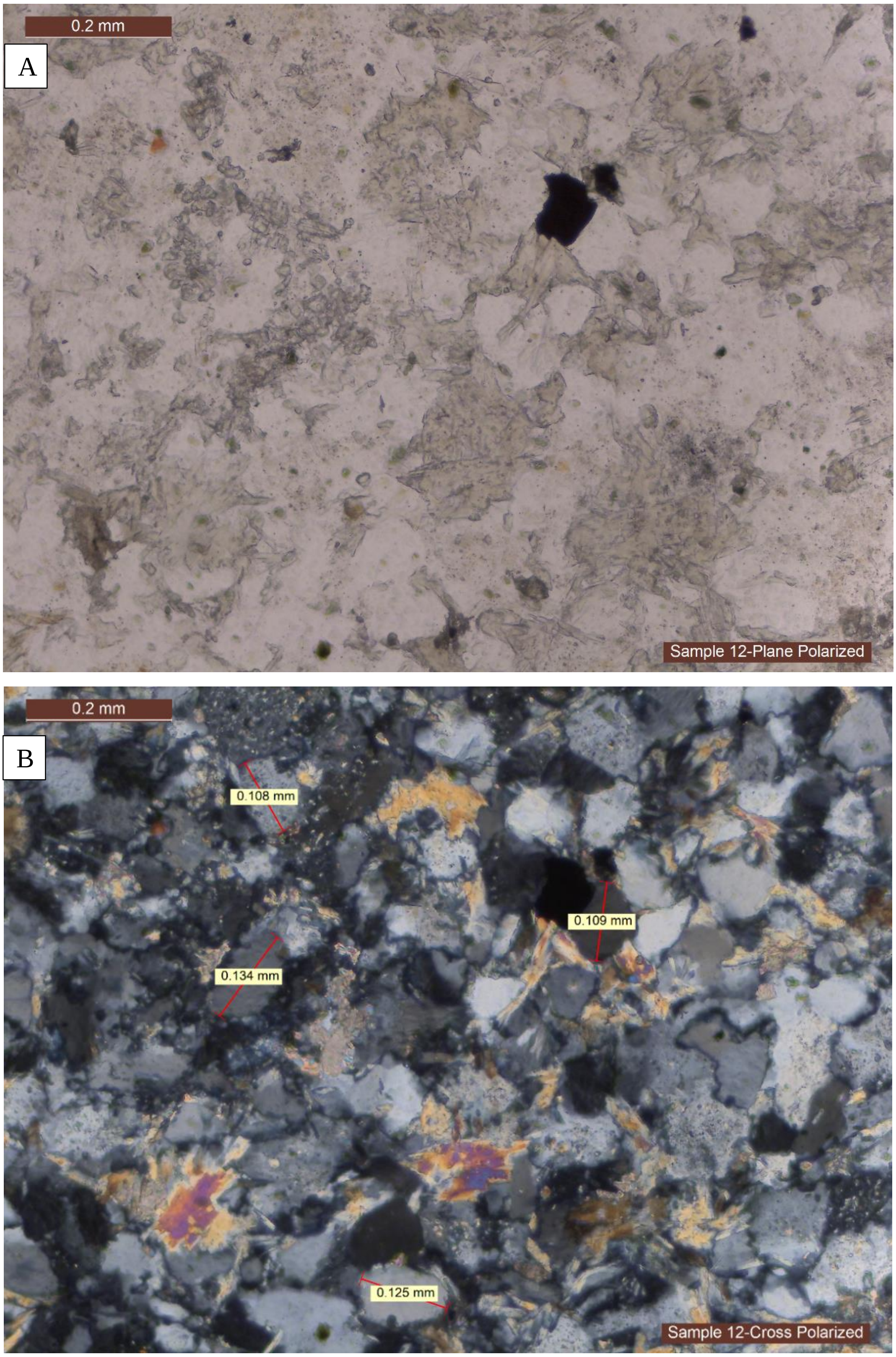


FIGURE 27: S12, Siltstone of F1. (A) Plane polarized light (B) Cross polarized light. Angular looking quartz grains due to overgrowth of cement. It indicate the rock has been heavily lithified. Presence of Muscovite (orange colour) between quartz grains. Opaque mineral – Hametite. Feldspar – dusty/dirty looking compared to quartz grains (top left).

Outcrop 2 (Teluk Chek Dendang)

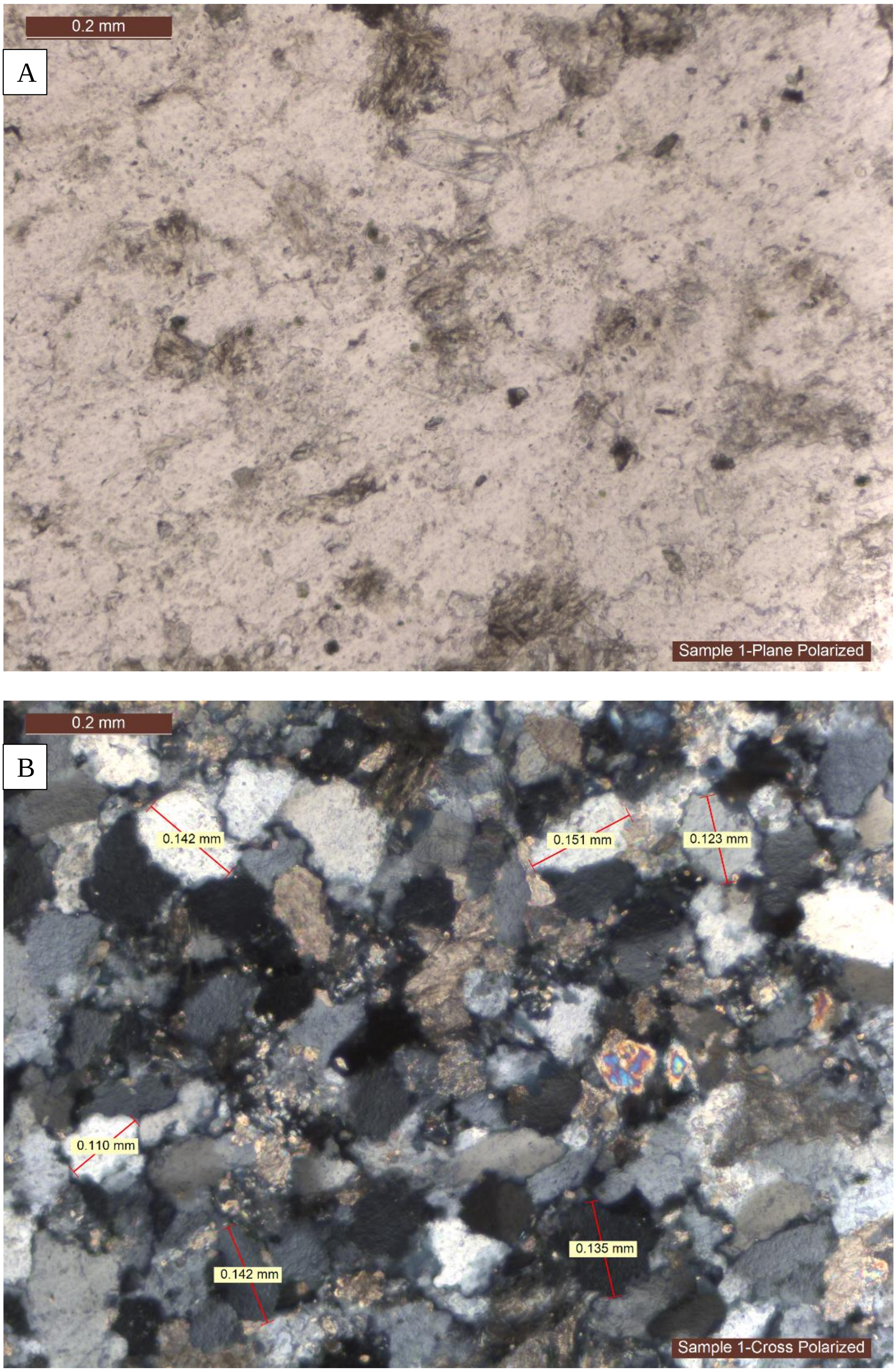


FIGURE 28: S1, Siltstone of F1. (A) Plane polarized light (B) Cross polarized light. Quartz (grey and colourless) and muscovite (orange-high relief) grains. Note the effects of compaction: a tight-fitting arrangement of grains, some interpenetration and squashing of grains.

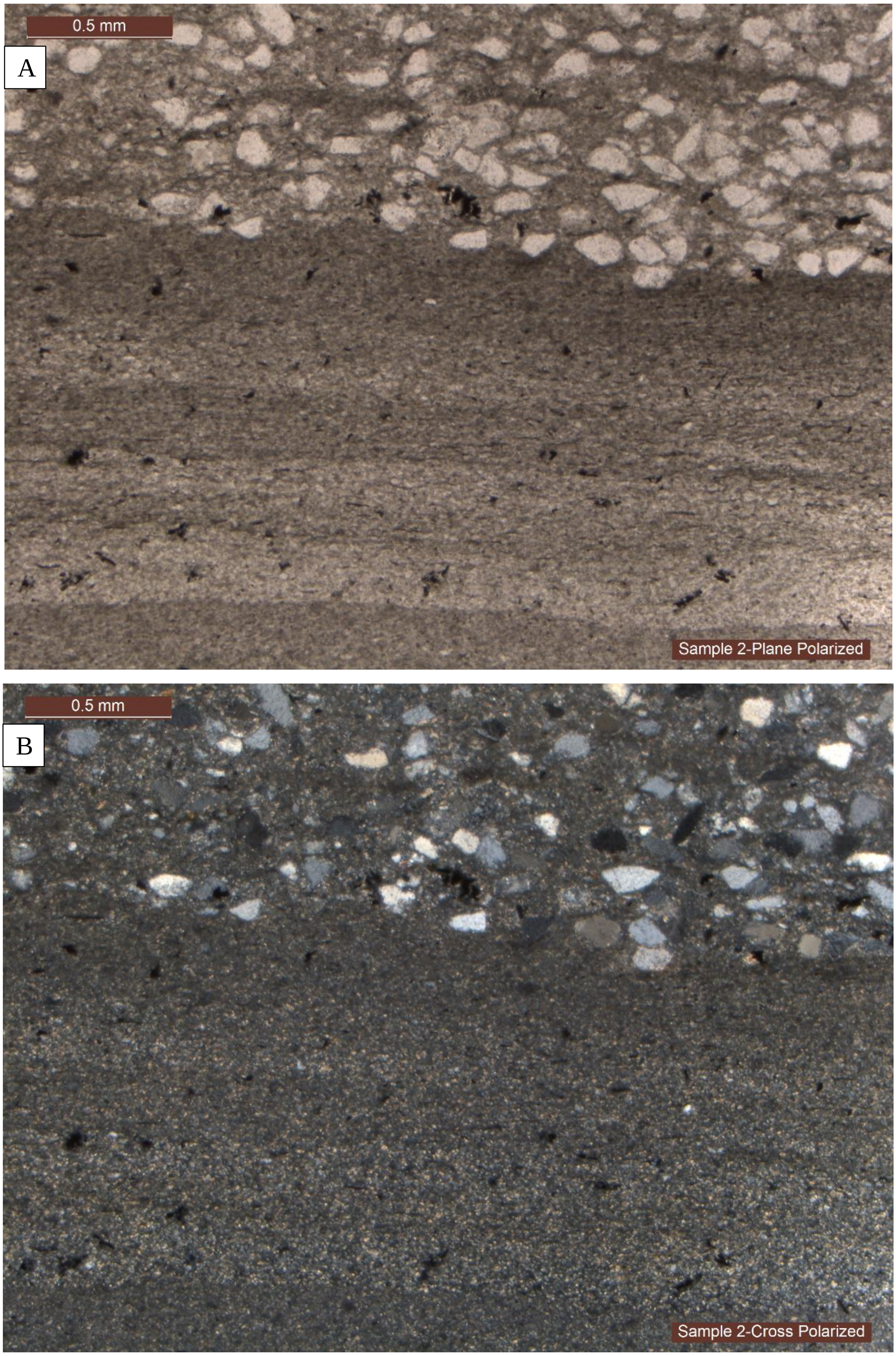


FIGURE 29: S2 of F4. Lamination in mudstone. (A) Plane polarized light (B) Cross polarized light. Silt (top) and mudstone (bottom). Silt layer mostly made up of angular quartz grains. Mudstone layer composed of clay mineral showing lamination within the mud layer itself. Opaque mineral is Hametite.

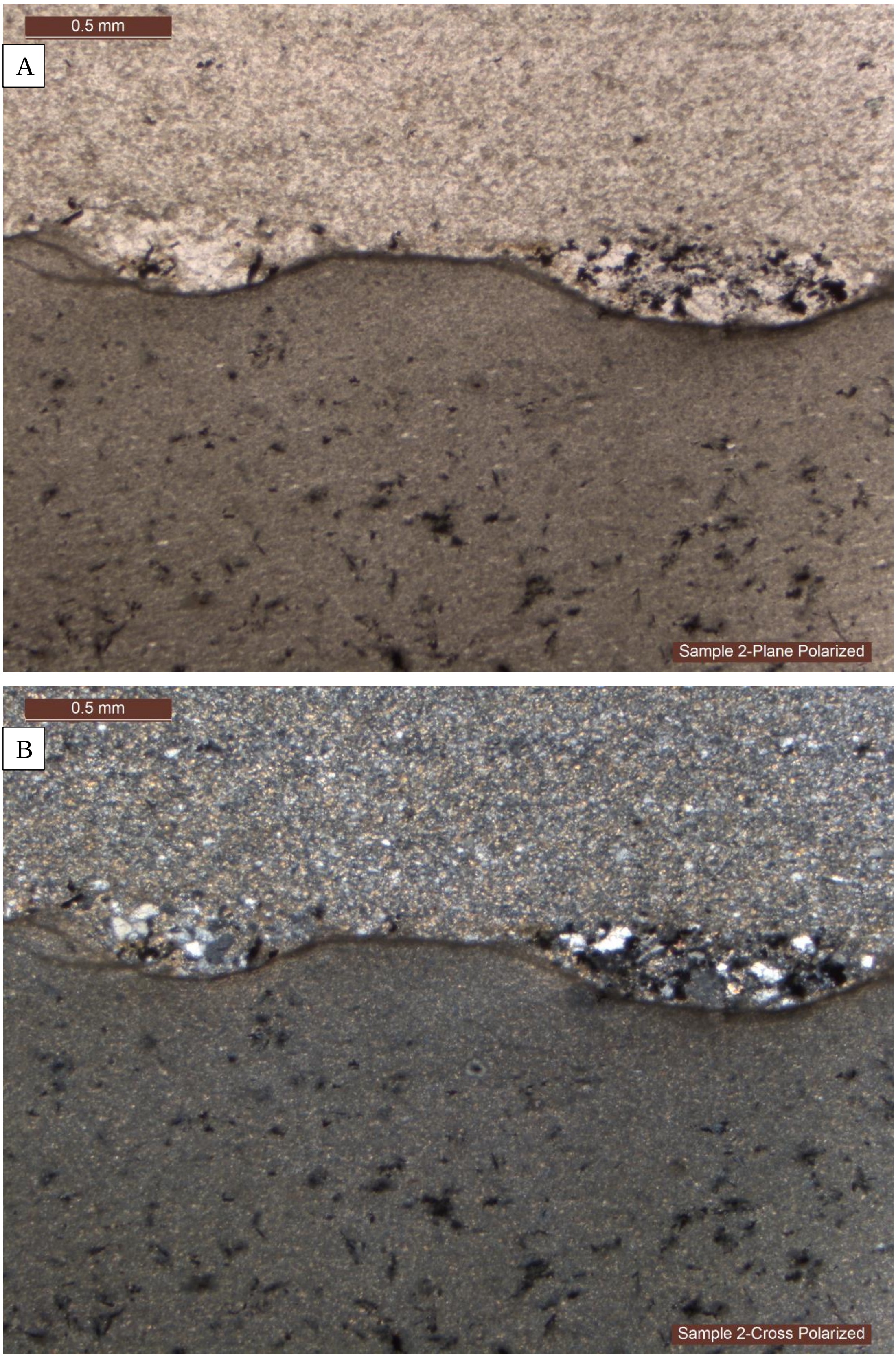


FIGURE 30: S2 of F4. Lamination in mudstone showing scours features. (A) Plane polarized light (B) Cross polarized light. The scours features are characterized by the cutting of bedding planes and lamination in underlying sediments. Slightly coarser sediments occurs within the scours. Scours structures represent short-lived erosion events.

Outcrop 3 (Teluk Chek Dendang)

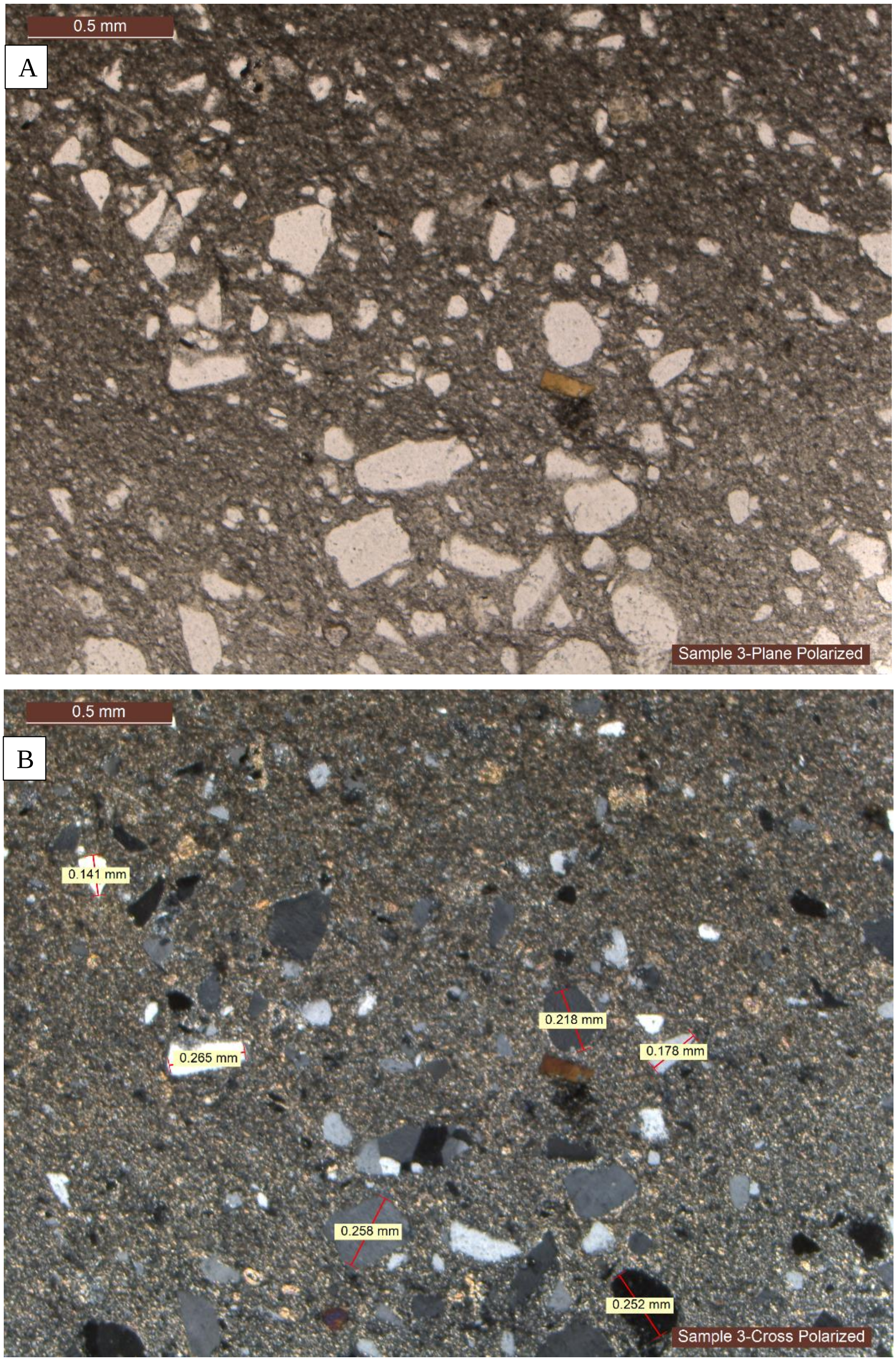


FIGURE 31: S13. Mudstone. (A) Plane polarized light (B) Cross polarized light. Matrix supported. Angular quartz grains. Quartz fragment (middle) composed of quartz grains enclosed as one grain. Biotite mica (brown). Small quartz grains as the cement for the mudstone.

Outcrop 6 (Tanjung Malai)

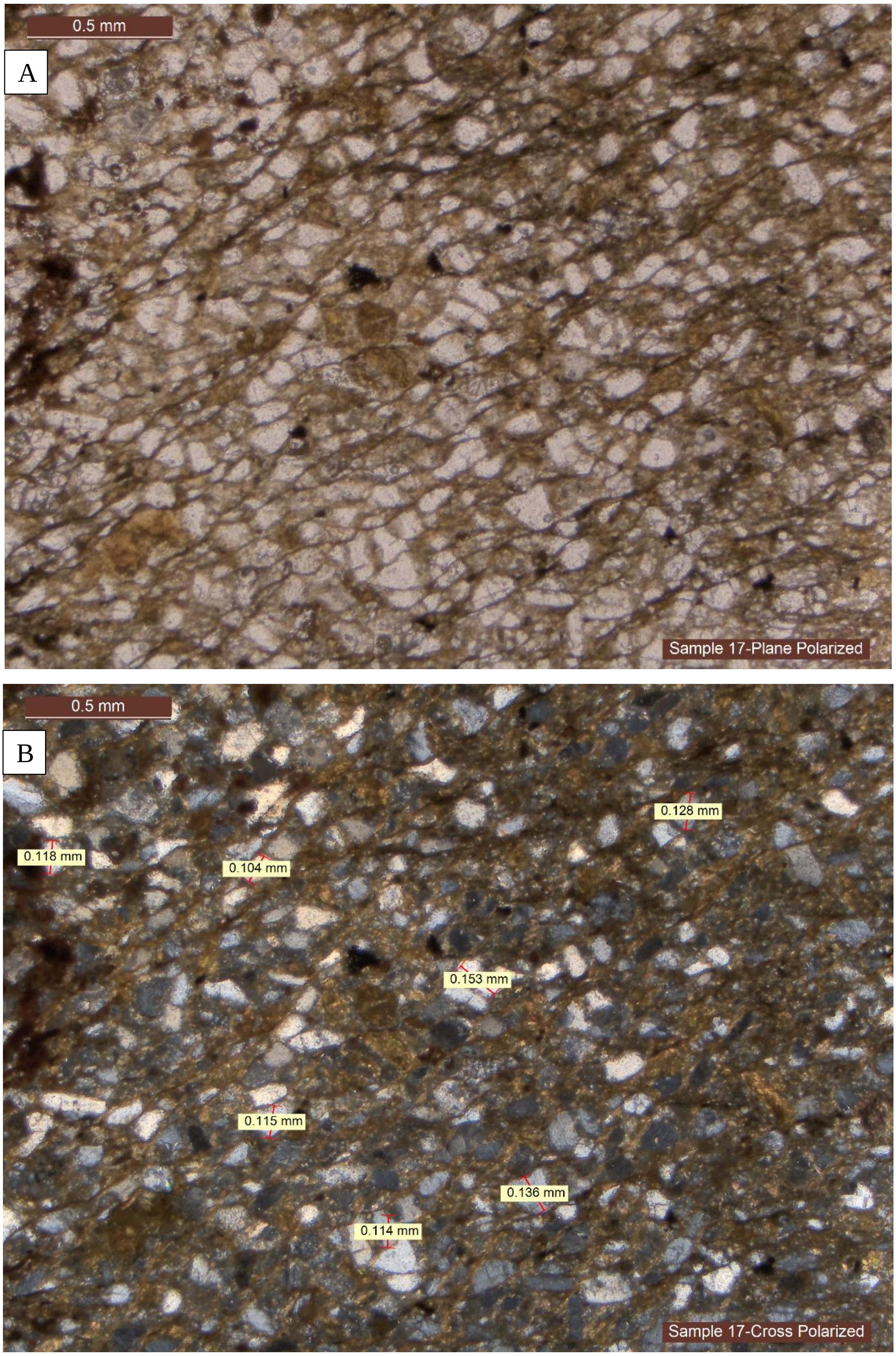


FIGURE 32: S17. (A) Plane polarized light (B) Cross polarized light. Mudstone/shale showing preferred orientation of clay minerals and micas parallel to the bedding. The texture is the result of deposition of clay flakes parallel to bedding.

Outcrop 7 (Tanjung Malai)

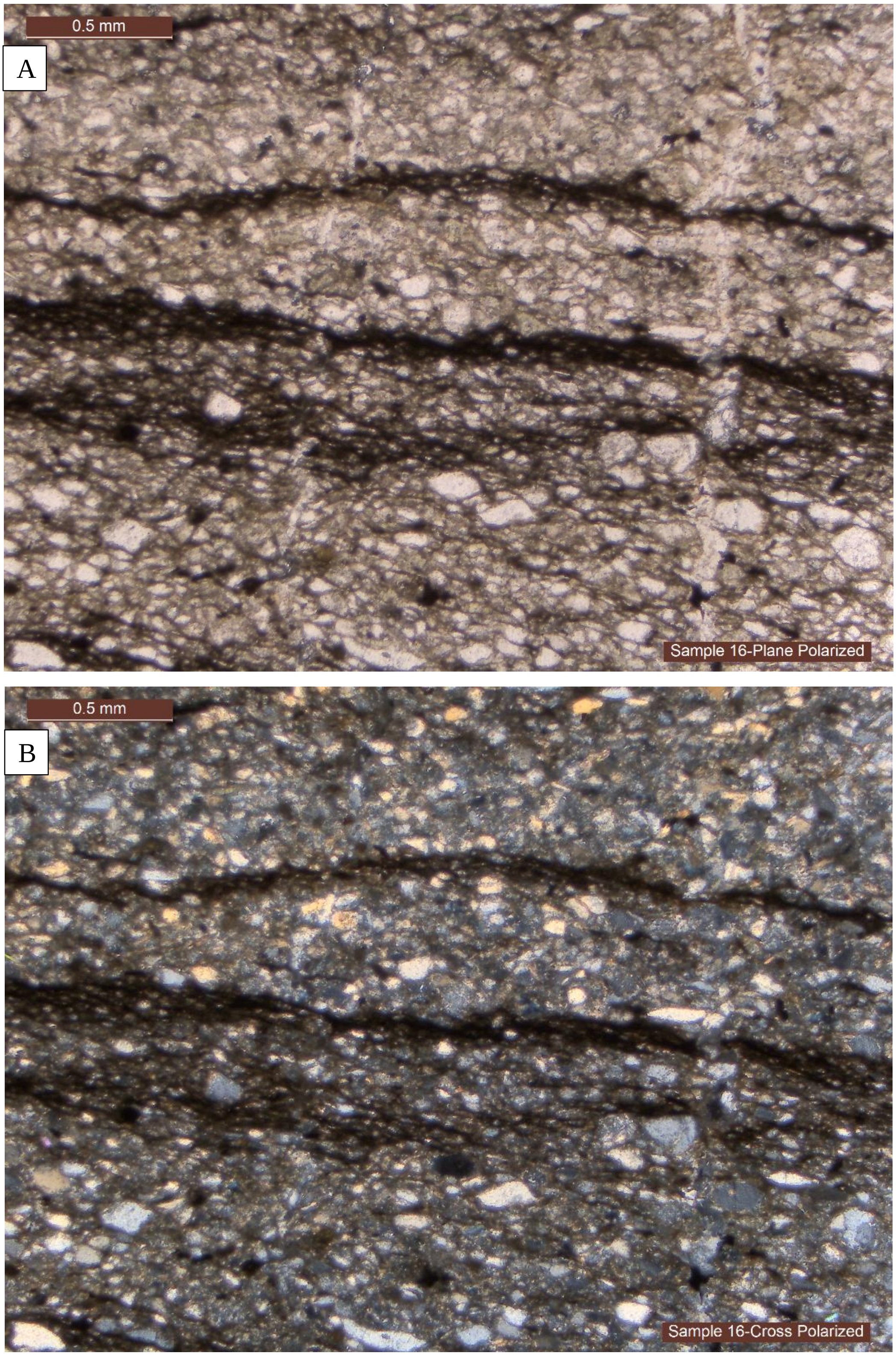


FIGURE 33: S16. Laminated mudstone. (A) Plane polarized light (B) Cross polarized light. Angular quartz grains laminated with clay minerals (dark stripes). The lamination show slightly undulating. Quartz grains follow the clay minerals orientation due to compaction.

Outcrop 8 (Tanjung Malai)

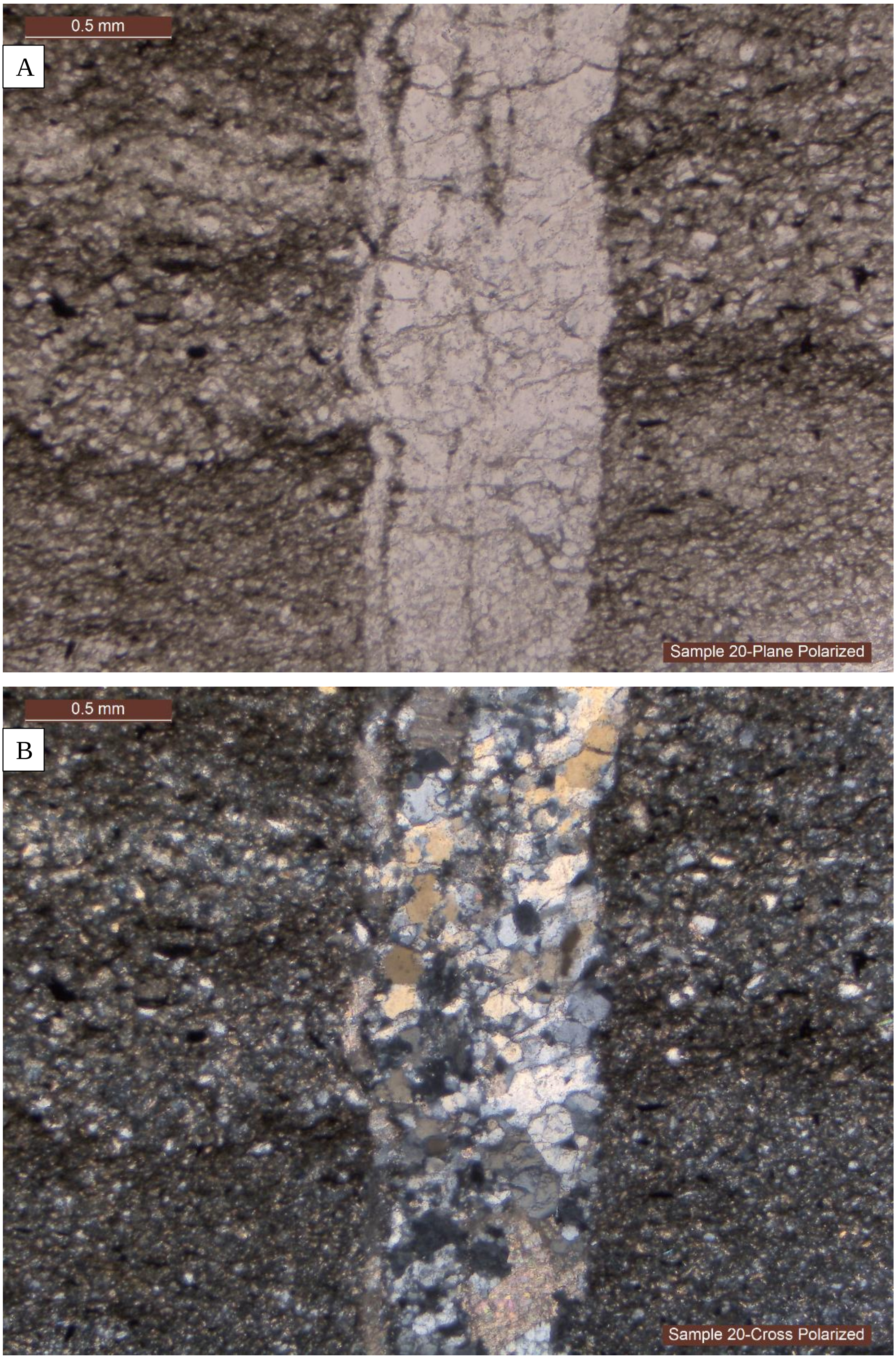


FIGURE 34: Quartz vein within laminated mudstone. Quartz grains of the vein is larger than mudstone.

5.3.1.1. Thin Section Description

Singa Formation is mainly composed of black mudrock. Black colour of mudrock reflect the organic content in the rock. Black mudrock indicate high organic content. The main constituents of mudrocks are clay minerals and silt-grade quartz.

Most of the sedimentary structure of mudrock in Singa Formation possesses lamination with siltstone when observed under petrographic microscope. Shale also observed under petrographic microscope where the mud is laminated and fissile. The grains were oriented parallel to the bedding.

General description of the minerals present are as follow:

Quartz

Quartz grains usually possesses angular shape. The grain size ranging from 0.04mm to 0.4mm. Very fine grained quartz grain act as the cement for the mudrock. In shale, the quartz grains align along the bedding/lamination plane (FIGURE 29 and FIGURE 32). Most of quartz grains in siltstone are compacted where the quartz grains penetrate in other quartz grains. It shows very tight arrangement of the quartz grains (FIGURE 27 and FIGURE 28).Quartz veins also occur in mudrock. The quartz veins are younger compared to the mudrock. When rocks break and form small openings, water enters from the adjacent rocks. The quartz from the adjacent rock dissolved in the water and precipitate within the fracture as veins (FIGURE 34).

Clay minerals

Micaceous minerals is predominantly muscovite. Muscovites are colourless in plane polarized light and shows orange colour in cross polarized light. Usually found as micaceous flakes or tablets with irregular outlines (FIGURE 27). Another micaceous minerals present is biotite. Biotite is very rare in mudrock. The colour is typically brown in plane polarized light. It found as tabular grains (FIGURE 31). Clay minerals are difficult to distinguish in thin section because of their fine crystal size.

Other minerals

Feldspar are generally present in very low concentration in mudrocks. When present in mudrock, it appears as tiny anhedral grains which not easily distinguishable under microscope. Hametite appears as opaque mineral in plane polarized light. Hametite is common as finely disseminated grains in many clastic sedimentary rocks.

5.3.2. X-Ray Fluorescence Result

The analysis of major and trace elements in geological materials by X-Ray Fluorescence is possible due to the atoms behaviour when they interact with radiation. When the individual atoms are excited by an external energy source, it emit X-Ray Photons of a characteristic energy or wavelength. By counting the number of photons of each energy emitted from a sample, the element present may be identified and quantified.

Result of elements and oxides of the samples are as follow:

TABLE 7: XRF result of Sample 1 (Siltstone)

ELEMENT	CONCENTRATION (%)
Si	54.7
Ca	18.3
Fe	8.52
K	7.28
Al	5.28
Mg	1.44
P	1.29
Ti	1.22

OXIDES	CONCENTRATION (%)
SiO2	68.8
CaO	10.8
Al2O3	6.68
Fe2O3	4.73
K2O	3.95
MgO	1.73
P2O5	1.35
TiO2	0.738

TABLE 8: XRF result of Sample 2 (Finely laminated mudstone)

ELEMENT	CONCENTRATION (%)
Si	46.6
Fe	16.9
K	12.1
Ca	9.09
Al	8.59
Mg	2.02
Ti	1.97
P	1.13

OXIDES	CONCENTRATION (%)
SiO2	59.9
Al2O3	10.9
Fe2O3	9.56
K2O	7.08
CaO	5.97
MgO	2.32
P2O5	1.41
TiO2	1.4

TABLE 9: XRF result of Sample 3 (Black mudstone)

ELEMENT	CONCENTRATION (%)
Si	41.9
Fe	19.8
K	12.9
Ca	9.46
Al	8.98
Mg	2.17
Ti	1.95
P	1.15

OXIDES	CONCENTRATION (%)
SiO2	55.2
Fe2O3	12.3
Al2O3	11.2
K2O	7.95
CaO	6.51
MgO	2.59
TiO2	1.46
P2O5	1.41

TABLE 10: XRF result of Sample 11 (Finely laminated mudstone)

ELEMENT	CONCENTRATION (%)
Si	43.6
Fe	18.8
K	12.7
Ca	9.09
Al	8.8
Ti	1.9
Mg	1.68
P	1.18

OXIDES	CONCENTRATION (%)
SiO2	57
Fe2O3	11.5
Al2O3	10.8
K2O	7.69
CaO	6.04
MgO	1.97
TiO2	1.4
P2O5	1.39

TABLE 11: XRF result of Sample 13 (Black mudstone)

ELEMENT	CONCENTRATION (%)
Si	40.4
Fe	25
K	12.9
Al	9.63
Ca	5.62
Ti	1.92
Mg	1.69
P	1.02

OXIDES	CONCENTRATION (%)
SiO2	53.6
Fe2O3	16.2
AlO3	11.9
K2O	8.21
CaO	4.03
MgO	2.01
TiO2	1.59
P2O5	1.28

5.3.2.1. X-Ray Fluorescence Description

Based on the result, the main composition of most of the sample is Silica (Si). It correspond to their oxides which show the compound of Silicon Dioxide (SiO_2). It represent the chemical formula for quartz. The samples contain quartz grains as their primary mineral that made up the whole rock itself.

The other possible mineral contain in the rock samples is Hametite. This is shown by the concentration of iron (Fe) is high after Silica (Si). This also indicates by the result of the oxides which gives the compound of iron (III) oxide (Fe_2O_3). The chemical formula for Hametite is Fe_2O_3. Thus, Hametite is a common mineral that made up clastic sedimentary rock. It usually occurs as finely disseminated grains within the sedimentary rock.

Other elements that resulted from the XRF which also high concentration amount are Potassium, Calcium and Aluminium. These 3 elements are possible compound that made up clay minerals. However, it is not easily to identify the specific clay minerals based on the elements and oxides.

5.3.3. X-Ray Diffraction Result

X-Ray Diffraction is to investigate crystalline material structure, including atomic arrangement, crystallite size, and imperfections of rock sample since the early 1900's. An experiment performed with X-rays established the three prevailing concepts of X-ray diffraction that:

1. Atomic particles within crystals are arranged in orderly, three-dimensional, repeating patterns;
2. These regular arrangements have spacing's of approximately the same dimensions as the wavelength of X-rays and therefore, because diffraction does take place;
3. X-rays are wavelike in nature.

Bragg equation relates the angle of diffraction with the wavelength and d spacing or particle width and is stated as:

$$2d \sin \emptyset = n\lambda$$

Where;

d = spacing between rows of atoms

$\emptyset$ = angle of incidence between glass slide and x-ray beam

n = integral number relating to wavelengths

λ = wavelength

X-Ray Diffraction analysis is most widely used for the identification of unknown crystalline materials. For instance, minerals and inorganic compounds.

Based on the result obtained, interpretation on the peak was done. The peaks on the result was interpreted based on the library within the software of the instrument. Knowledge on the compound within the sample is necessary to do the interpretation.

Result of the peak are as follow:

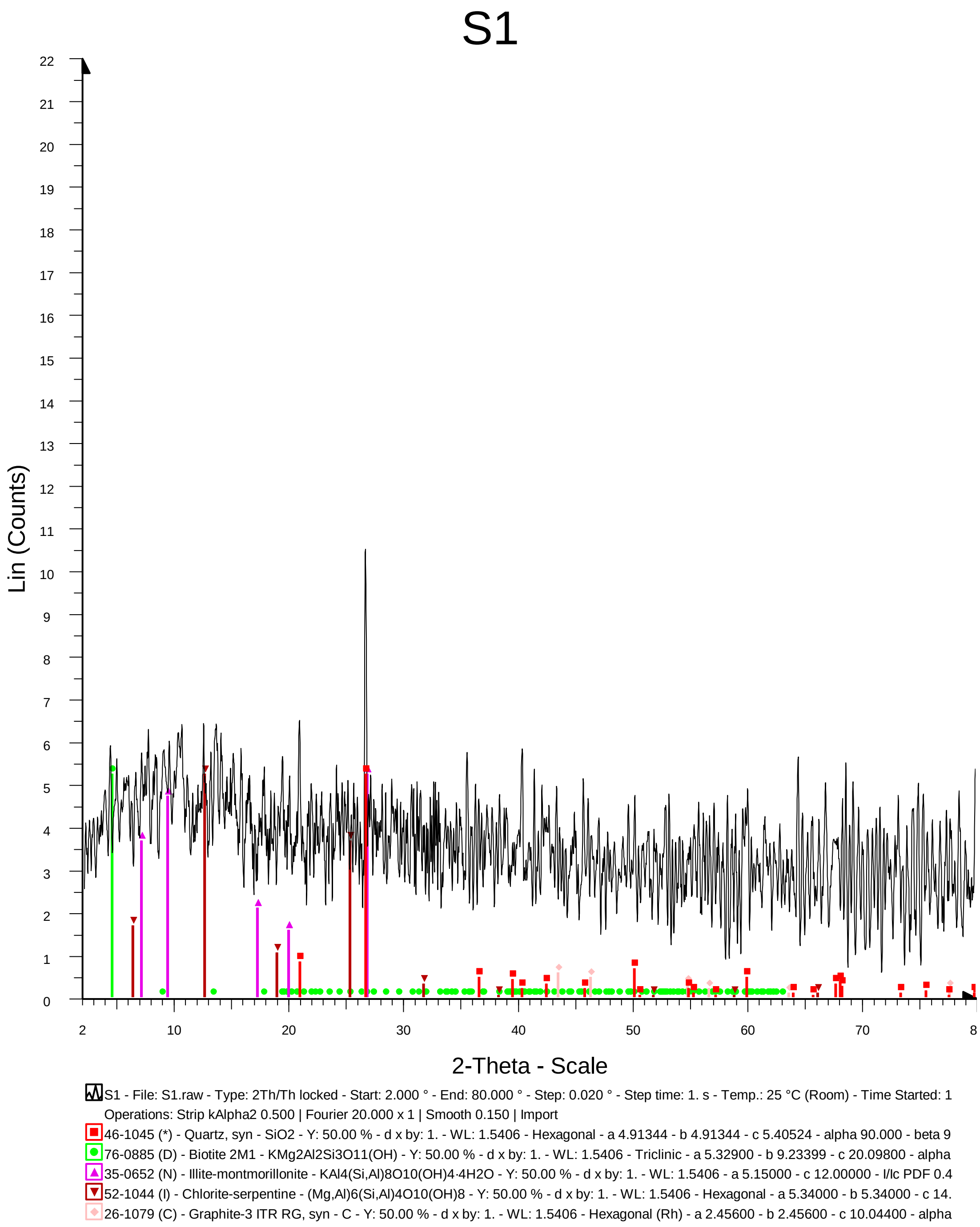


FIGURE 35: XRD result for S1 at Outcrop 2, Teluk Chek Dendang. The mineral content in this sample are Quartz, Biotite, Illite-montmorillonite, and Graphite.

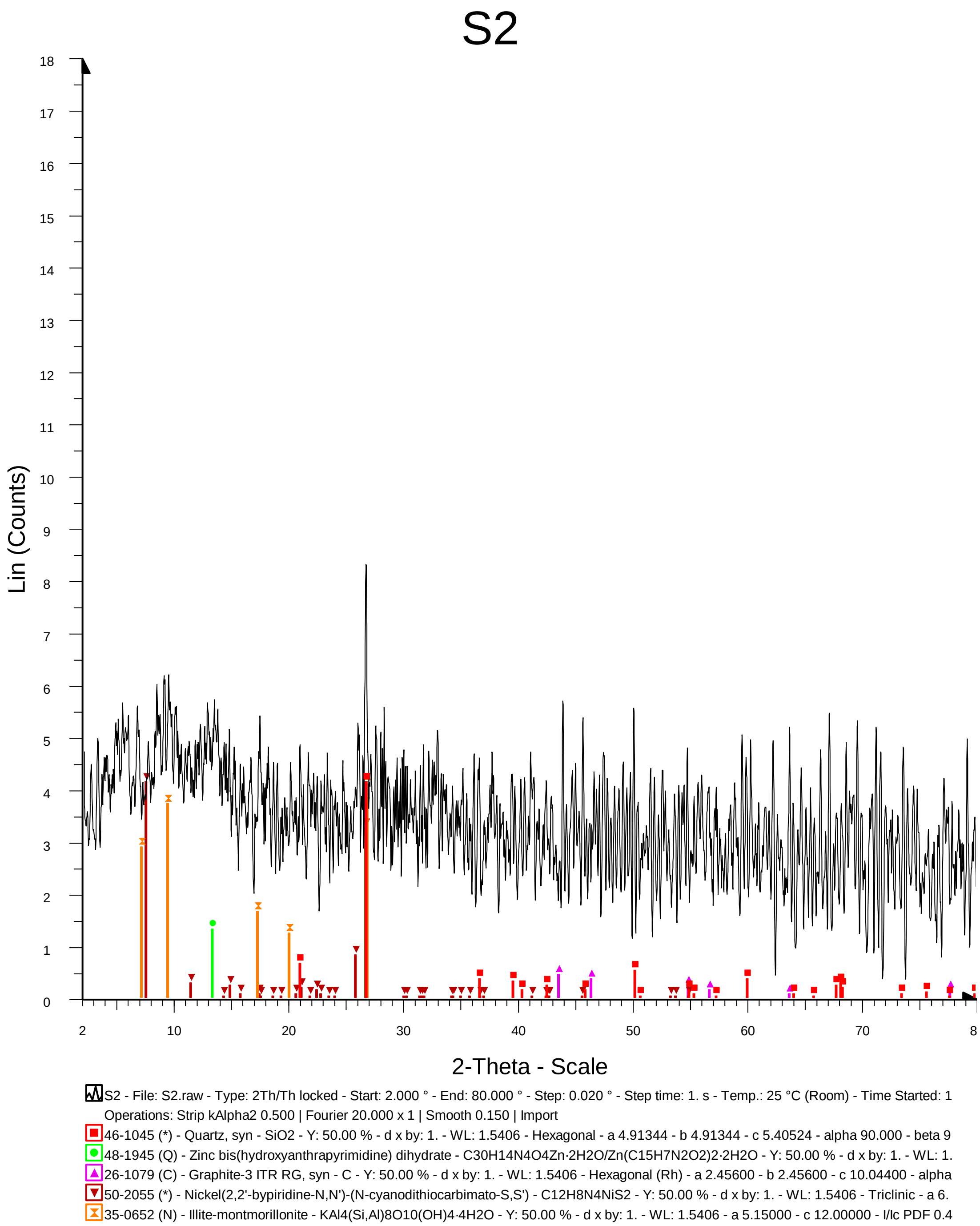


FIGURE 36: XRD result for S2 at Outcrop 2, Teluk Chek Dendang. The mineral content in S2 sample are Quartz, illite-montmorillonite, and Graphite.

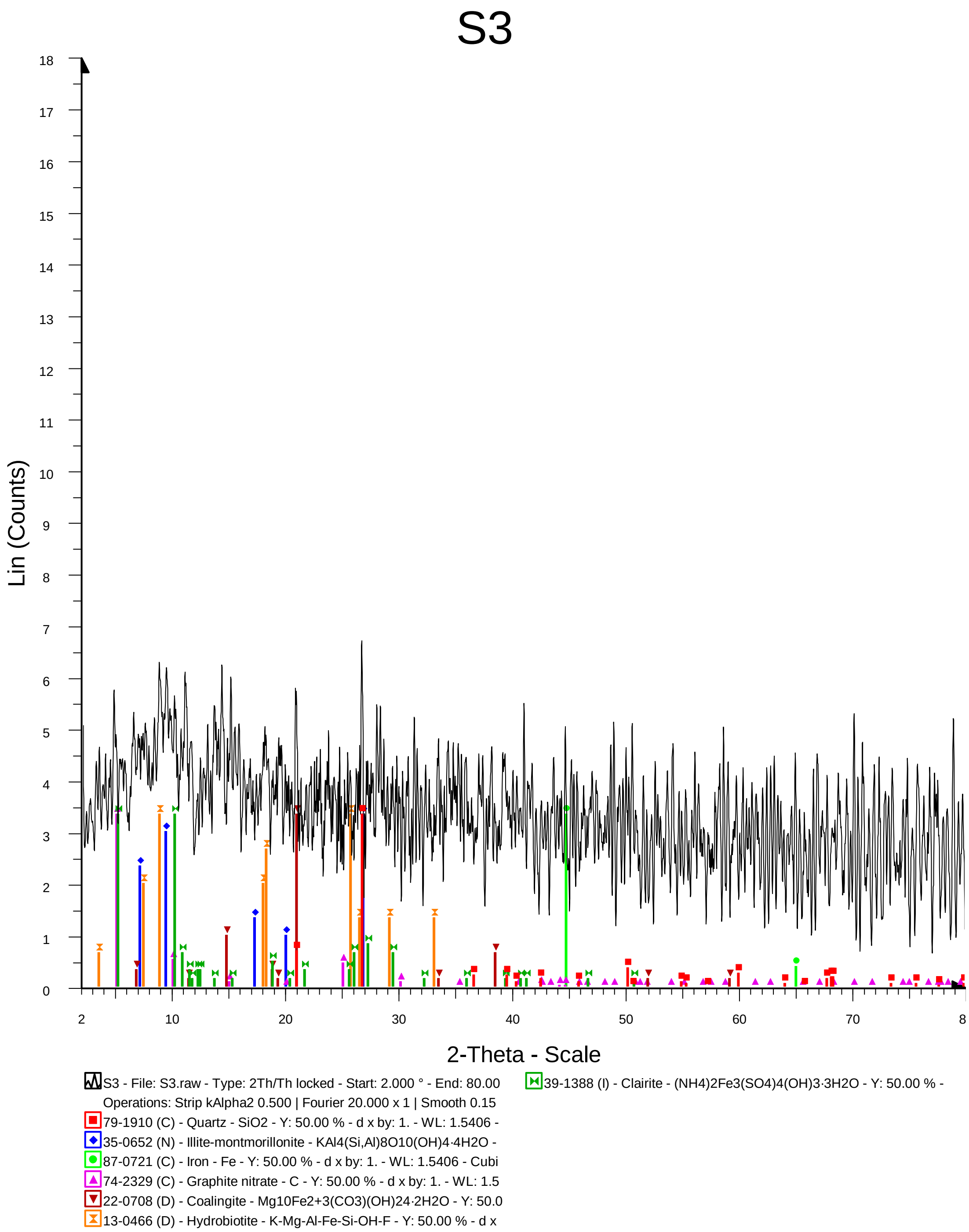


FIGURE 37: XRD result for S3 at Outcrop 2, Teluk Chek Dendang. The minerals content in this sample are Quartz, Iron, Illite-montmorrilonite, and Graphite.

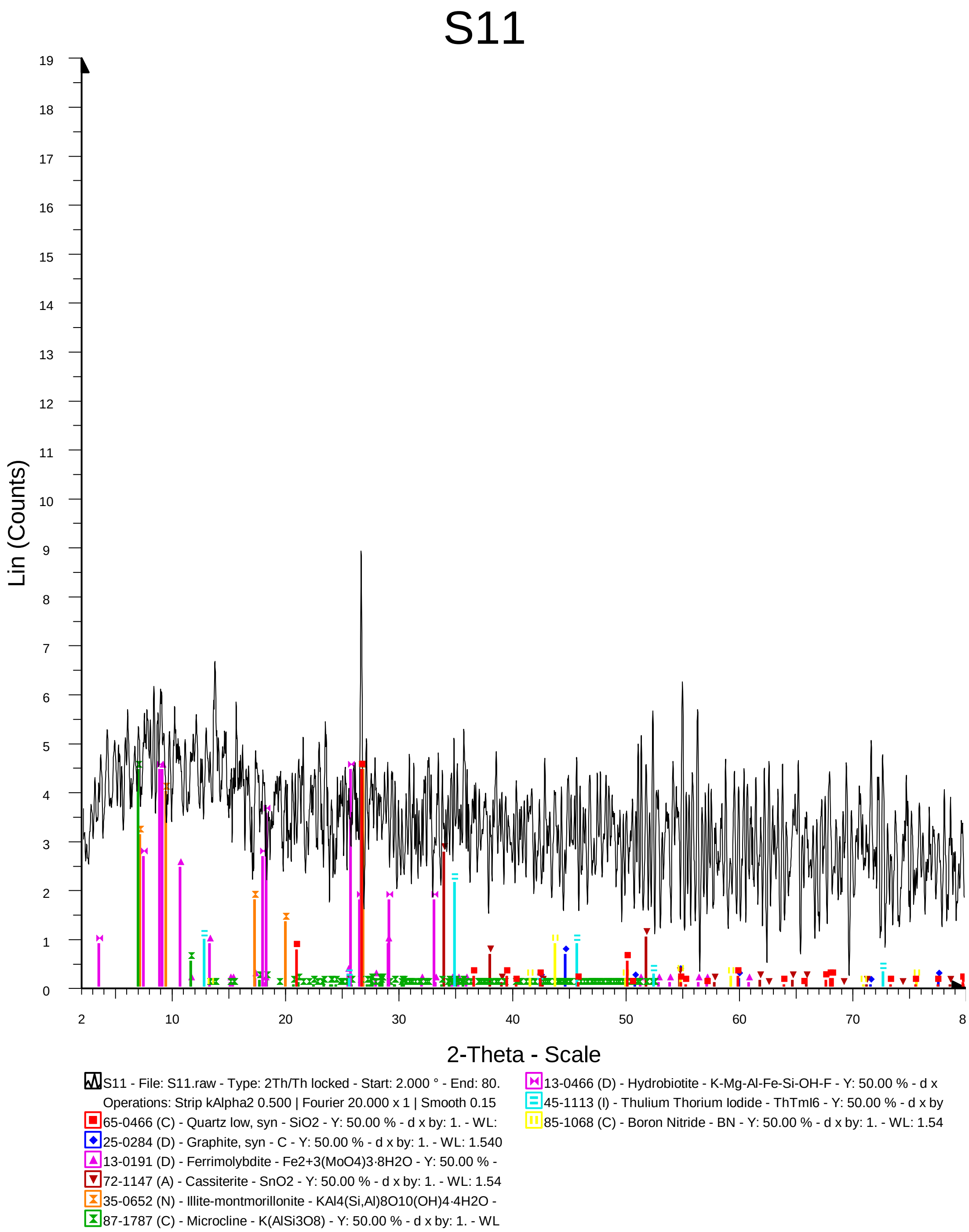


FIGURE 38: XRD result for S11 at Outcrop 1, Teluk Chek Dendang. The mineral content in this sample are Quartz, Illite-montmorrilonite, Cassiterite and Microcline.

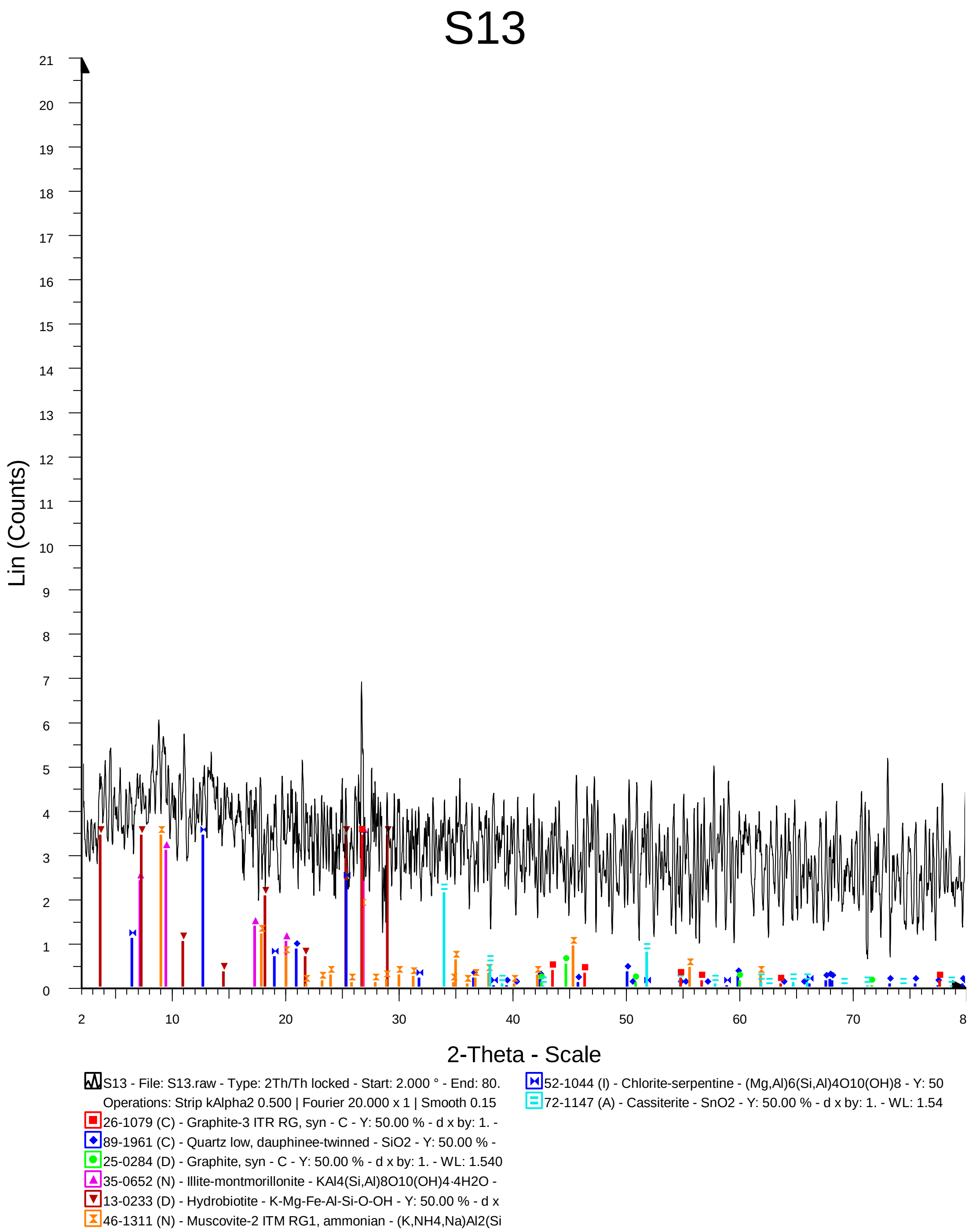


FIGURE 39: XRD result for S13 at outcrop 1, Teluk Chek Dendang. The mineral content in this sample are Quartz, Illite-montmorrilonite, Graphite, Muscovite and Cassiterite.

5.4. INTERPRETATION

5.4.1. Facies Association

The facies association of the study area is determined by the interpretation based on the sedimentology log constructed during the fieldwork. Thus, from the sedimentology log there are two distinct facies association are identified. The facies association are:

FA 1: Offshore Facies Association

FA 1 observed from the sedimentology log is less than 3m thick. Commonly it consists of black and dark-grey mudstone. FA 1 is characterised by a coarsening upward succession from thick mudstone into thin interbedded sandstone, siltstone and mudstone. The thick black mudstone facies are very hardly to recognise the structure. The thick black mudstone grades upward into mudstone interbedded with cm-thick dark-grey siltstone layers and cm-thick rippled dark-grey siltstone lenses (1.5 – 2cm). Within the siltstone layers, it displays planar and undulating lamination. The bed boundaries are usually display sharp contact, with occasionally diffuse or undulating contact. The silt lenses sometimes display load cast structures at the top of the bed and display a ripple like structure at the bottom of the bed.

FIGURE 40: Offshore facies association (FA 1) showing mud dominance with planar and gently lamination.

Interpretation:

FA 1 is interpreted as wave- and storm-influenced offshore deposits based on the mudstone facies dominance with thin sandstone beds displaying wave- and storm-generated structures (ripples lenses, planar lamination and cross lamination). The mudstone facies indicates a low energy in which there is no flow or almost no flow of a quiet water environment. It deposited in almost stagnant water where clay particles settle down with suspension. It indicates that it deposited in environment where the strong water movement is not affecting the succession. The thin interbedded siltstone indicate occasional disturbance by high energy events which transport and deposit coarser sediments. During high-energy storm events, the nearshore area is eroded and reworked by the waves. Fine-grained material is transported seaward or basinward by suspension by waves and currents. As these basinward directed currents lose their transport capacity, very fine-grained silt and sand is deposited as thin sandy lamination or beds and lenses of silts within the muddy environment. Meanwhile, during fair-weather periods, the clay particles were deposited by suspension. The mudstone facies reflect a constant deposition over an extended period of time. The depositional setting is below fair-weather wave base mainly supported by quite thick succession of muddy sediments with occasional storm deposition that cause the occurrence of silt or sand tail lenses in the muddy environment.

FA 2: Lower Shoreface Facies Association

FA 2 is characterised by interbedded very fine to fine grained sandstone of cm-thick and mudstone of cm-thick. FA 2 thickness is about 0.5m to 1m. Sandstone beds contain silt of very fine grained of dark-grey colour with planar to slightly undulation thin lamination. The siltstone beds ranging 2cm to 3.5cm are laterally extensive with some of the siltstone lenses ranging 1.5cm to 2cm in thickness are pinching out. Within the sandstone beds also contains massive sandstone displaying structureless sandstone beds. The sandstone beds shows undulating contact or gradual change between two different facies, but it also display sharp contact occasionally. Sometimes, the hummocky cross-lamination could be observed within the sandstone beds.

FIGURE 41: Lower shoreface facies association (FA 2) showing coarsening upward sequence from interbedded sandstone with mudstone to massive sandstone facies.

Interpretation:

The sedimentary structure of FA 2 represents a distal wave- and storm-dominated environment based on the occurrence of more frequent planar- and cross-lamination or hummocky cross stratification of sandstone and siltstone. The slightly thicker grain size indicate that the energy that carry the sediments is higher (increase in velocity). It could be that the environment still have the influenced of calm and quiet environment due to the occurrence of mud within this facies association. Some of the siltstone are quite laterally extensive indicate that it is deposited within a high energy event for quite a period of time. The pinching lenses of silt indicates that the energy is slowly decreasing. The thickness of sandstone or siltstone beds suggest that the deposition of the sediments occurs during the periods of high sediment input. Thus, the depositional setting of FA 2 is slightly above fair-weather wave base which represent that it occurs in the lower shoreface zone. The evidence is from the occurrences of interbedded of mudstone and sandstone where the sandstone bed is slightly thicker than the mudstone beds.

5.4.2. Facies Succession

The facies succession of Singa Formation at the Teluk Chek Dendang outcrop is generally a prograding wave- and storm-influences succession which composed of offshore and lower shoreface facies association. It was represented by repeated coarsening upward trend with muddier environment dominance. Thus, it indicates that the succession is deposited in a calm and quiet environment with almost no flow or almost stagnant water. However, the muddy environment was introduces with sand and silt occasionally due to the influenced of wave and storm events. It may be caused by the prograding of delta or the river is shifting laterally causing more sediments input to the succession. Therefore, the possible environment of deposition of this facies succession is the coastal environment specifically the prodelta depositional environment (FIGURE 42).

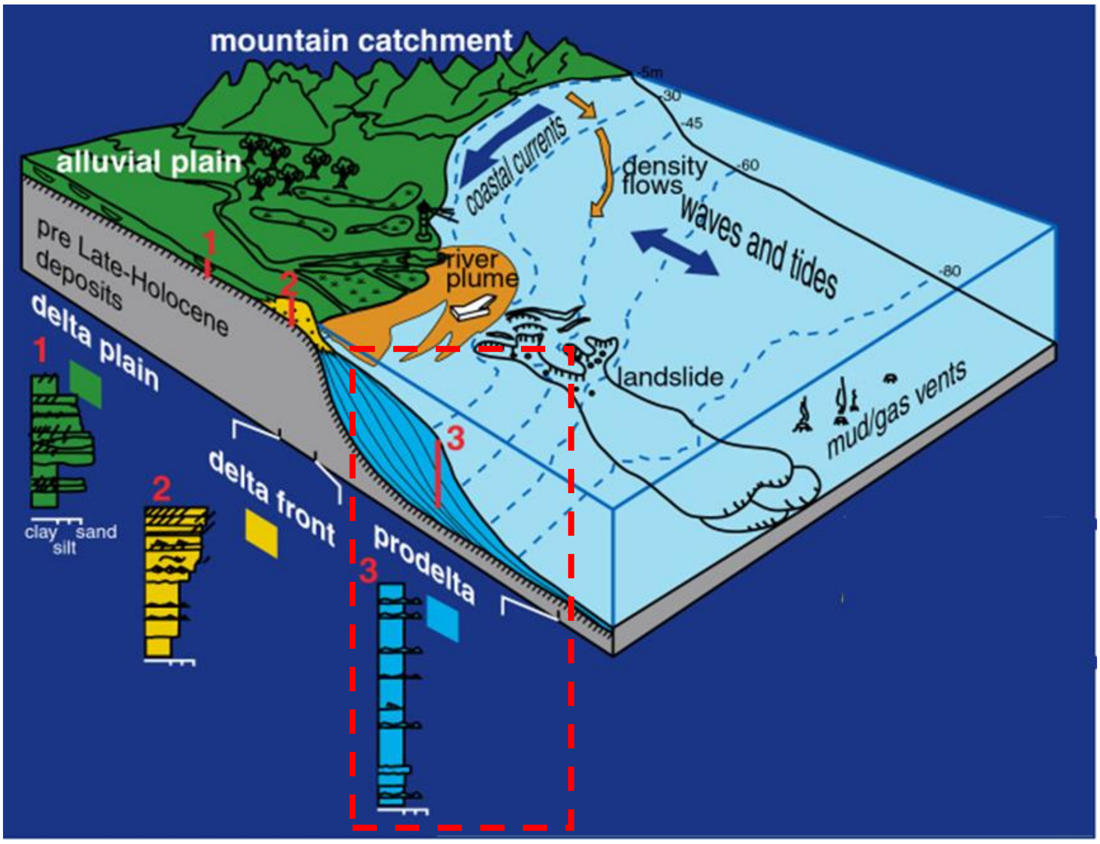


FIGURE 42: Proposed depositional environment for the study area, Prodelta depositional environment. (Source: European Coordination on Mediterranean and Black Sea Prodelta

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

The Singa Formation in Langkawi Island is exposed at several location at the Southwestern of Langkawi Island. The location identified are at Teluk Chek Dendang, Tanjung Mali and Tanjung Malai. The study mainly focused at the Teluk Chek Dendang area.

i. A detailed sedimentological study and facies analysis of the Singa Formation at Teluk Chek Dendang, Langkawi indicates that the Singa Formation at Teluk Chek Dendang was deposited at coastal environment, specifically the prodelta depositional environment due to the influence of wave and storm events in a muddy environment. Two stratigraphic section logged at Teluk Chek Dendang and one at Tanjung Malai. Five different types of facies identified based on the stratigraphic section: 1) Massive siltstone facies-F1; 2) Finely laminated siltstone facies-F2; 3) Thick laminated mudstone facies-F3; 4) Finely laminated mudstone facies-F4; and 5) Black mudstone facies-F5. The succession of the Singa Formation at Teluk Chek Dendang is interpreted into two coarsening upward facies association. The facies association grades upward from an offshore facies association (FA 1) composed of black mudstone and finely laminates mudstone facies, into a lower shoreface facies association (FA 2) composed of finely lamination siltstone and massive siltstone facies.

ii. Petrographic analysis indicate that the main constituents of the Singa Formation at Teluk Chek Dendang are clay minerals and silt-grade quartz grains. Several micro-sedimentary structures also can be identified under polarizing microscope such as erosional features (scours) and fine lamination between mud and siltstone.

iii. Geochemistry analysis such as XRF and XRD also proved the rocks of Singa Formation consists of mainly quartz (SiO_2) and clay minerals. Based on XRF result it shows the concentration of quartz constituent is more than half of the total composition. XRD result show the possible clay minerals contains in the Singa Formation rock is illite-montmorrilonite.

6.2. RECOMMENDATION

Interpretation of the petrographic and geochemical analysis requires a lot of experience in dealing with minerals identification and geochemical analysis data. Thus, a lot of reading need to be done in order to have a detailed interpretation on the data required.

A few number of studies had been conducted on the Singa Formation in Langkawi Islands. The occurrence of dropstone or diamictite of the Singa Formation in certain area requires in depth study to determine the origin of the dropstone.

Since Singa Formation is widely spread in the Southwest and Northeast of Langkawi Islands, studies could be done to correlate the Singa Formation in Langkawi Islands with the Kubang Pasu Formation in Perlis and Kedah. Thus, the tectonic process can be deduce from the detailed studies on both formation.

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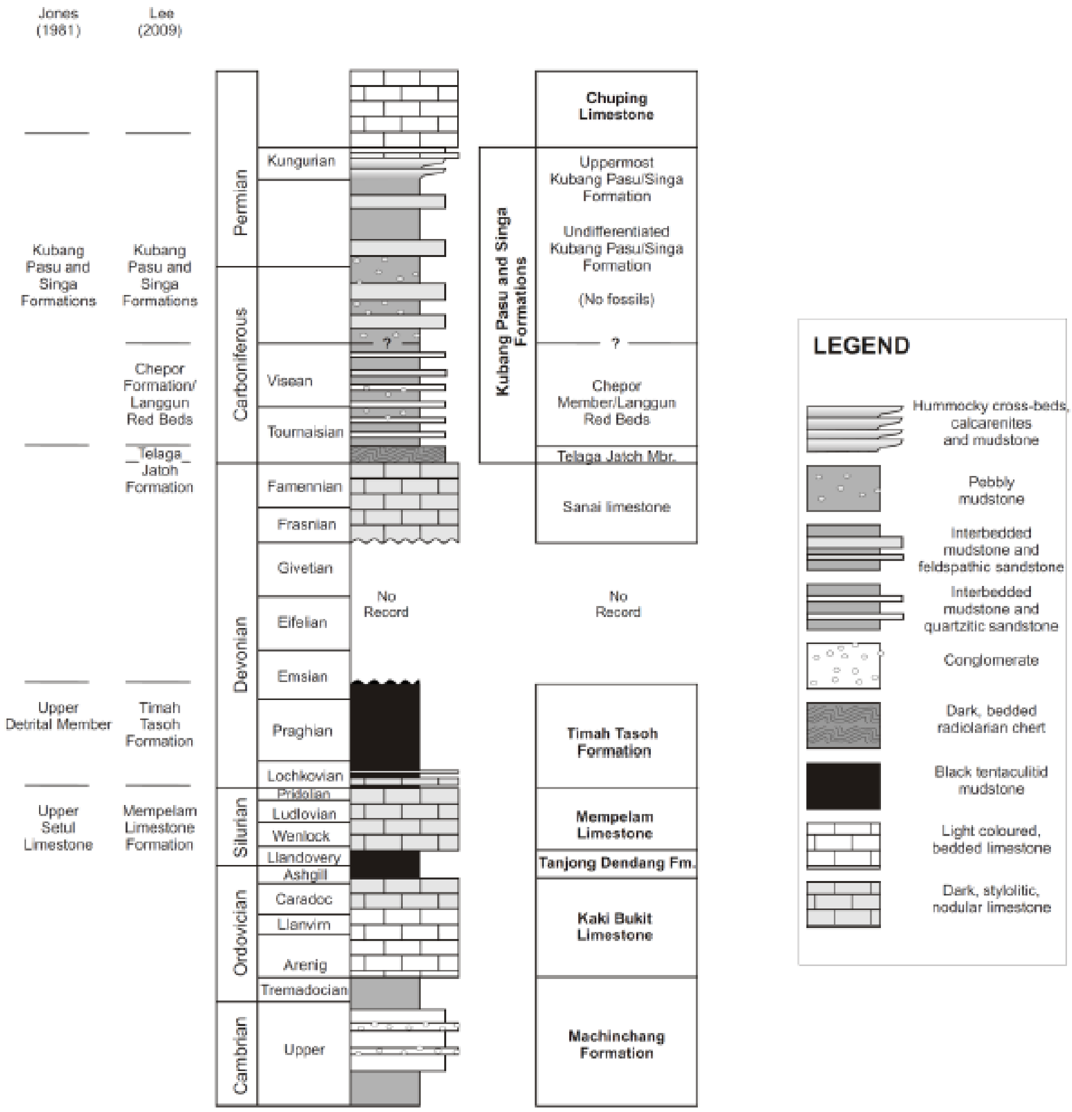
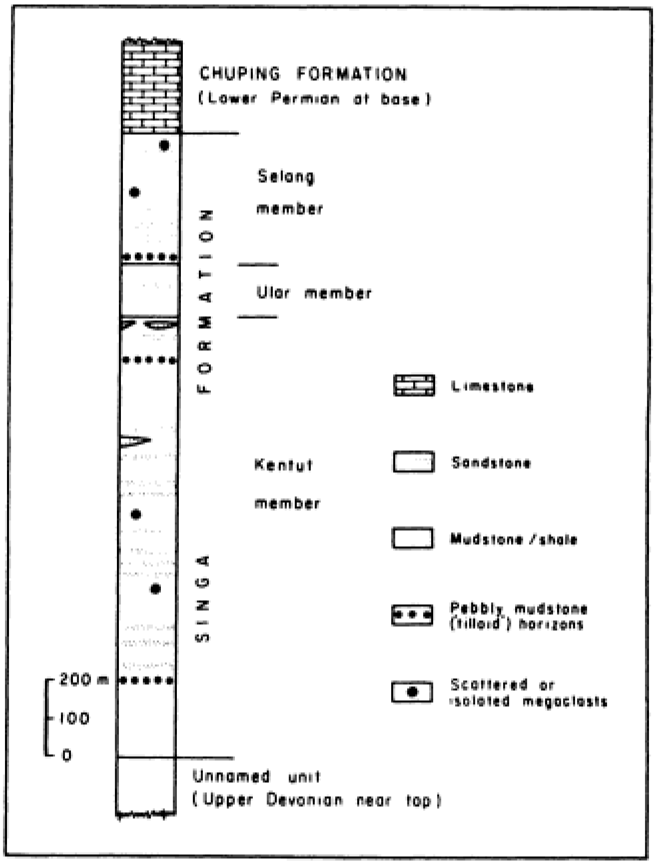
APPENDICES



Palaeozoic stratigraphy of Northwest Peninsular Malaysia (Meor *et al.*, 2013)



Stratigraphic section through the Singa Formation in the Langkawi Islands, northwest Malaya. (After Ahmad, 1973)